

Worldwide Spacecraft Crew Hatch History

S&MA Flight Safety Office

Safety & Mission Assurance Support Services Contract
OSMA Assessments Team
Informational Report

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Summary, Purpose and Background

The JSC Flight Safety Office has developed this compilation of historical information on spacecraft crew hatches to assist the Safety Tech Authority in the evaluation and analysis of worldwide spacecraft crew hatch design and performance.

The document is prepared by SAIC's Gary Johnson, former NASA JSC S&MA Associate Director for Technical. Mr. Johnson's previous experience brings expert knowledge to assess the relevancy of data presented. He has experience with six (6) of the NASA spacecraft programs that are covered in this document: Apollo; Skylab; Apollo Soyuz Test Project (ASTP), Space Shuttle, ISS and the Shuttle/Mir Program. Mr. Johnson is also intimately familiar with the JSC Design and Procedures Standard, JPR 8080.5, having been one of its original developers.

Observations and Findings

The observations and findings are presented first by country and organized within each country section by program in chronological order of emergence. A host of reference sources used to augment the personal observations and comments of the author are named within the text and/or listed in the reference section of this document. Careful attention to the selection and inclusion of photos, drawings and diagrams is used to give visual association and clarity to the topic areas examined.

Recommendations and Conclusions

Recommendations and conclusions are beyond the scope of this report and therefore are not applicable.

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1.0 History of United States' Spacecraft Crew Hatches

1.1 Mercury

Project Mercury was the first human spacecraft program of the U.S. and successfully completed nine (9) piloted missions. There was one event on the Mercury Redstone 2 (MR-2) mission that occurred shortly after landing, the entrance hatch pyrotechnic fired which caused the hatch to be jettisoned. Astronaut Gus Grissom was able to quickly exit the spacecraft and swim away. The recovery helicopter picked up Gus Grissom, but the Mercury capsule sank. The cause of the accident was not determined, it was reported by Astronaut Grissom that the initiator cap and safety pin were removed after landing, but the plunger was not depressed.

1.1.1 Entrance Hatch

"An entrance hatch, is located on the right side of the after body conical section as viewed from the crew member station. Entrance hatch construction, similar to the conical section construction consists of an inner and outer (beaded) skin seam welded together and reinforced with hat stringers. See Figures 1.1.1-a, and 1.1.1-b.

An explosive charge, molded in the hatch sill, is provided to quickly release the hatch and enable the astronaut to egress rapidly. An explosive charge initiator, located in the upper aft corner of the hatch is linked to an internal release control initiator.

Prior to the launch, the hatch is bolted and sealed into position with bolts; two corrugated shingles are installed over the hatch. The bolts are inserted through the entrance hatch sill which incorporates the explosive charge, [then] threaded into the spacecraft seal. A magnesium gasket, with inlaid rubber, forms the hatch seal when the hatch is bolted into position.

Two hatch shingles are attached to the hatch stringers, but in no manner are they attached to spacecraft shingles. (This enables the hatch to separate cleanly upon ignition of [the] hatch explosive charge.)"

Following impact, the astronaut removes: 1) the initiator cap from the internal release control initiator, and 2) the safety pin from the initiator plunger. By depressing the initiator plunger, the initiator's two spring-loaded firing pins strike the explosive charge percussion caps and detonate the explosive charge. This action explodes the hatch from the spacecraft.

An exterior hatch release control is provided to enable ground personnel to explode the hatch in the event the astronaut is unable to do so. Hatch retention springs, secured by pip pins, are incorporated on the inner side of the entrance hatch to prevent injury to ground personnel if the plunger is accidentally depressed from [inside the capsule].

Two pressure valves, located in the hatch enable pressurization and purging of the spacecraft during ground checkout operations". [McDonnell SEDR 104-18. NASA Project Mercury Familiarization Manual. 1962. June 1]



SEDR 104-18

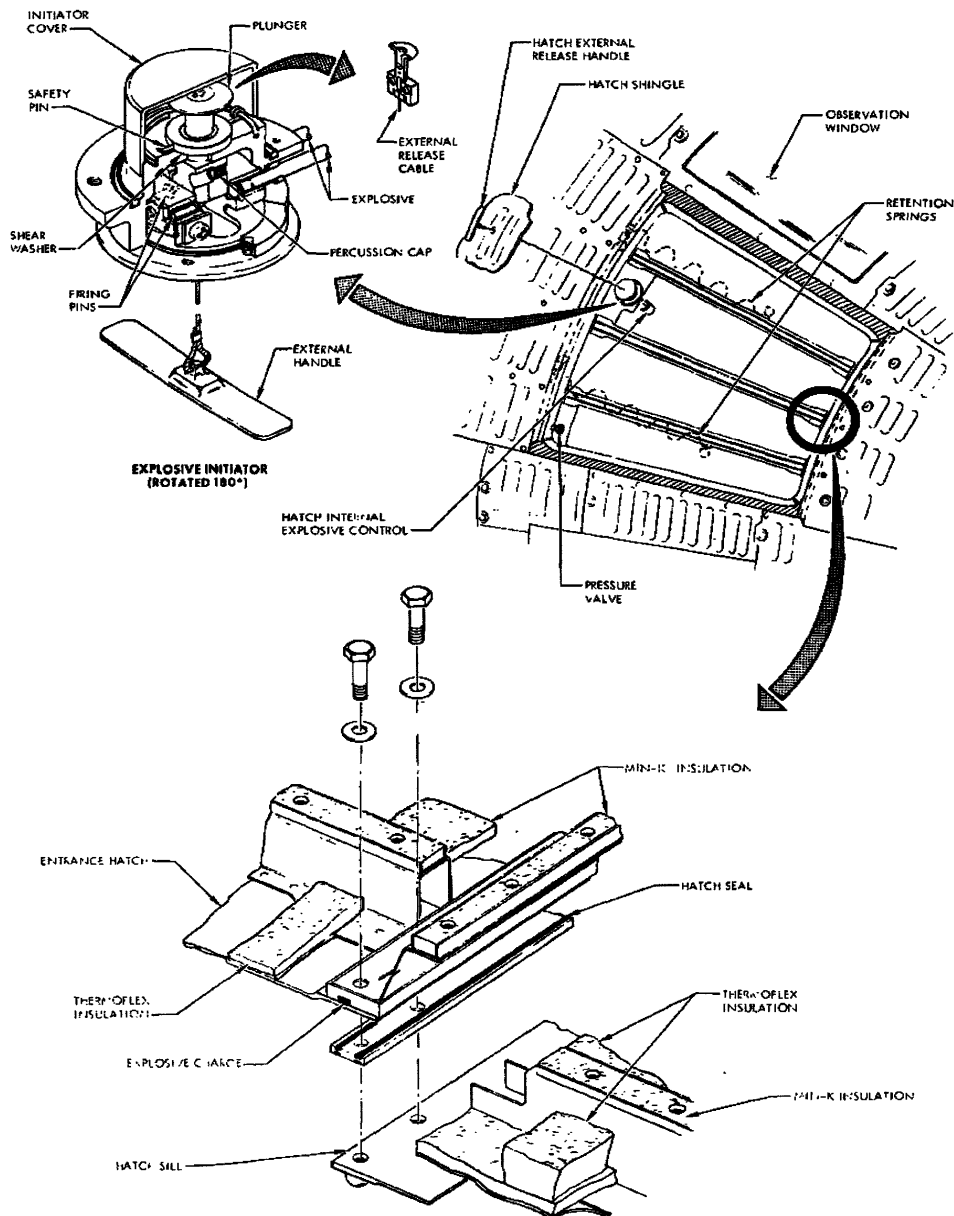
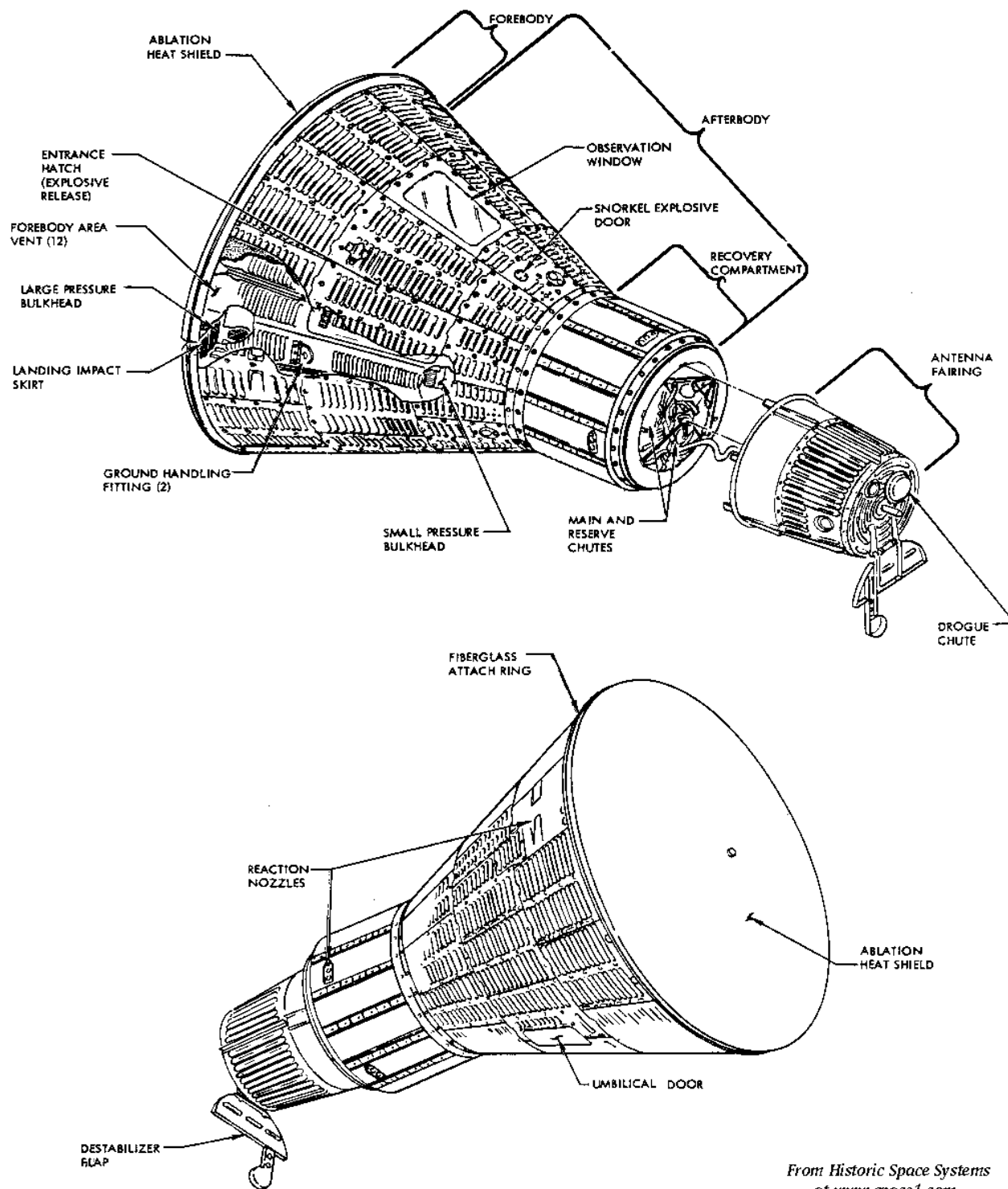


Figure 1.1.1-a Entrance Hatch



From Historic Space Systems
at www.space1.com

Figure 1.1.1-b Entrance Hatch (Exterior)

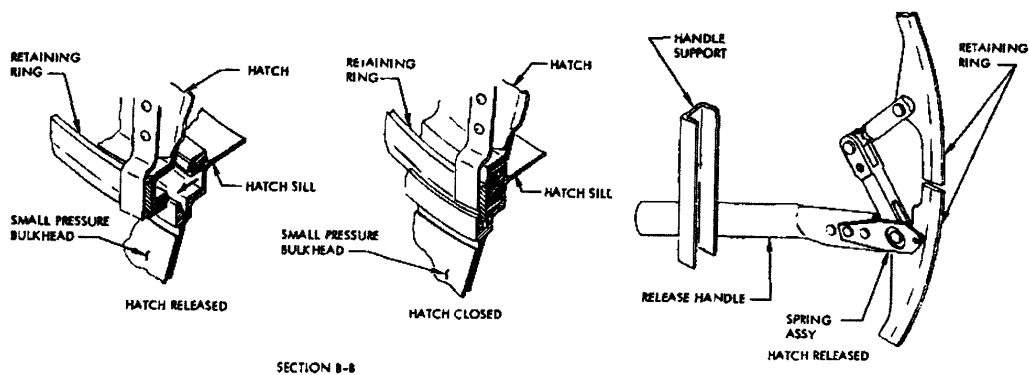
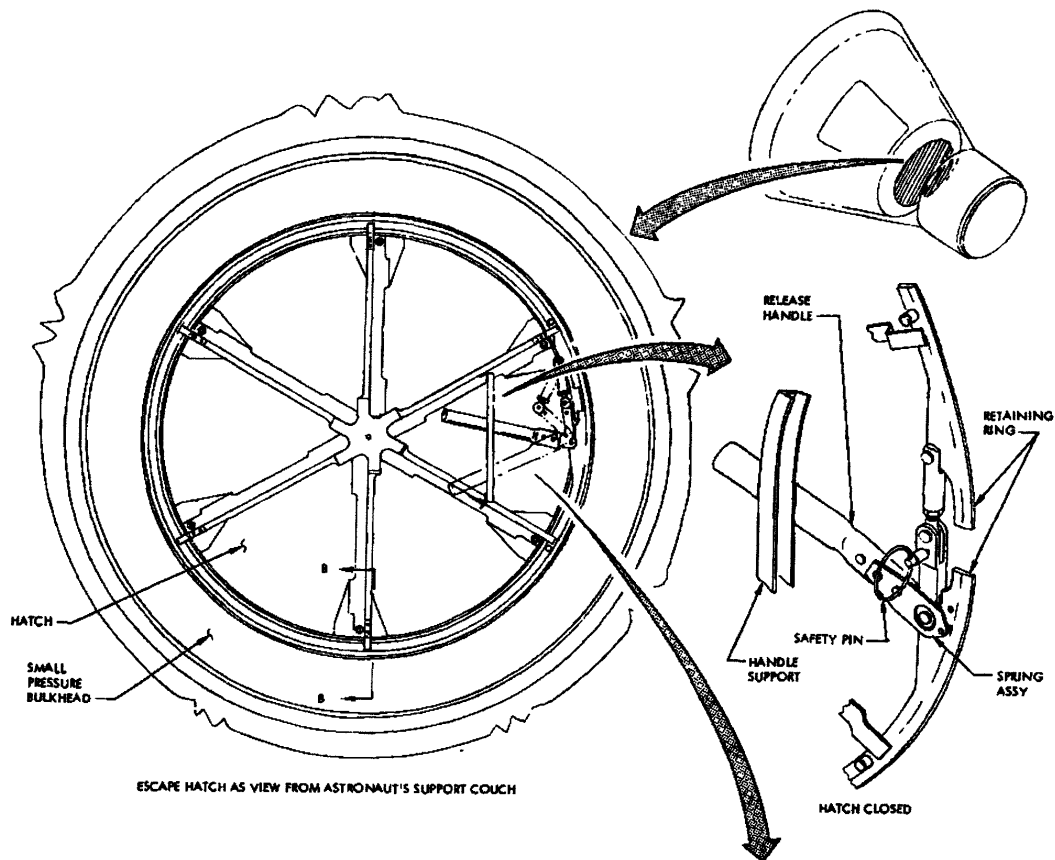
1.1.2 Escape Hatch

"A sealed escape hatch, Figure 1.1.2, which is externally actuated, is provided in the small pressure bulkhead to enable the astronaut's exit following spacecraft landing. The *shallowly concaved* escape hatch is constructed of a beaded aluminum skin that is spot welded to an inner skin; this is reinforced with structural "Z" shaped members.

The hatch outer flanged edge fits into the small pressure bulkhead sill and is held in place with a retaining ring. By raising the hatch handle, the retainer ring is expanded, which wedges the retainer ring between the bulkhead sill and the hatch flanged edge. This forces the hatch flange aft to provide a sealing action". [McDonnell SEDR 104-18. [NASA Project Mercury Familiarization Manual. (1962). June 1]



SEDR 104-18



1.2 Gemini

Project Gemini was the second human spacecraft program of the U.S. It was designed for rendezvous, docking, and extra-vehicular activity (EVA). The Gemini Program successfully completed 10 piloted missions. The crew consisted of a Command Pilot and Pilot. Design modifications included separate outward opening ingress and egress hatches.

1.2.1 Hatches

“Two (2) large structural hatches, Figure 1.2.1-a, are incorporated for sealing the cabin ingress or egress openings. The hatches are symmetrically spaced on the top side of the cabin section. Each hatch is manually operated by means of a handle and a mechanical latching mechanism; the hatches are hinged on the outboard side. In an emergency, the hatches are opened in a three (3) sequence operation employing pyrotechnic actuators. When initiated, the pyrotechnic actuators simultaneously unlock and open the mechanical latches, open the hatches, and supply hot gases to ignite the ejection seat rocket catapults.

An external hatch linkage fitting is incorporated to allow a recovery hatch handle to be inserted for opening the hatches from the outside. The recovery hatch handle is stowed on the main parachute adapter assembly; the assembly is located on the forward face of the reaction control system (RCS) section.

A hatch curtain, Figure 1.2.1-b, is stowed along the hinge of each hatch. After water landing, when the hatches are open, the curtains are engaged to help prevent water from entering the cabin”. [McDonnell SEDR 300 Volume 1. NASA Project Gemini Familiarization Manual. (1964). March 15]

SEDR 300

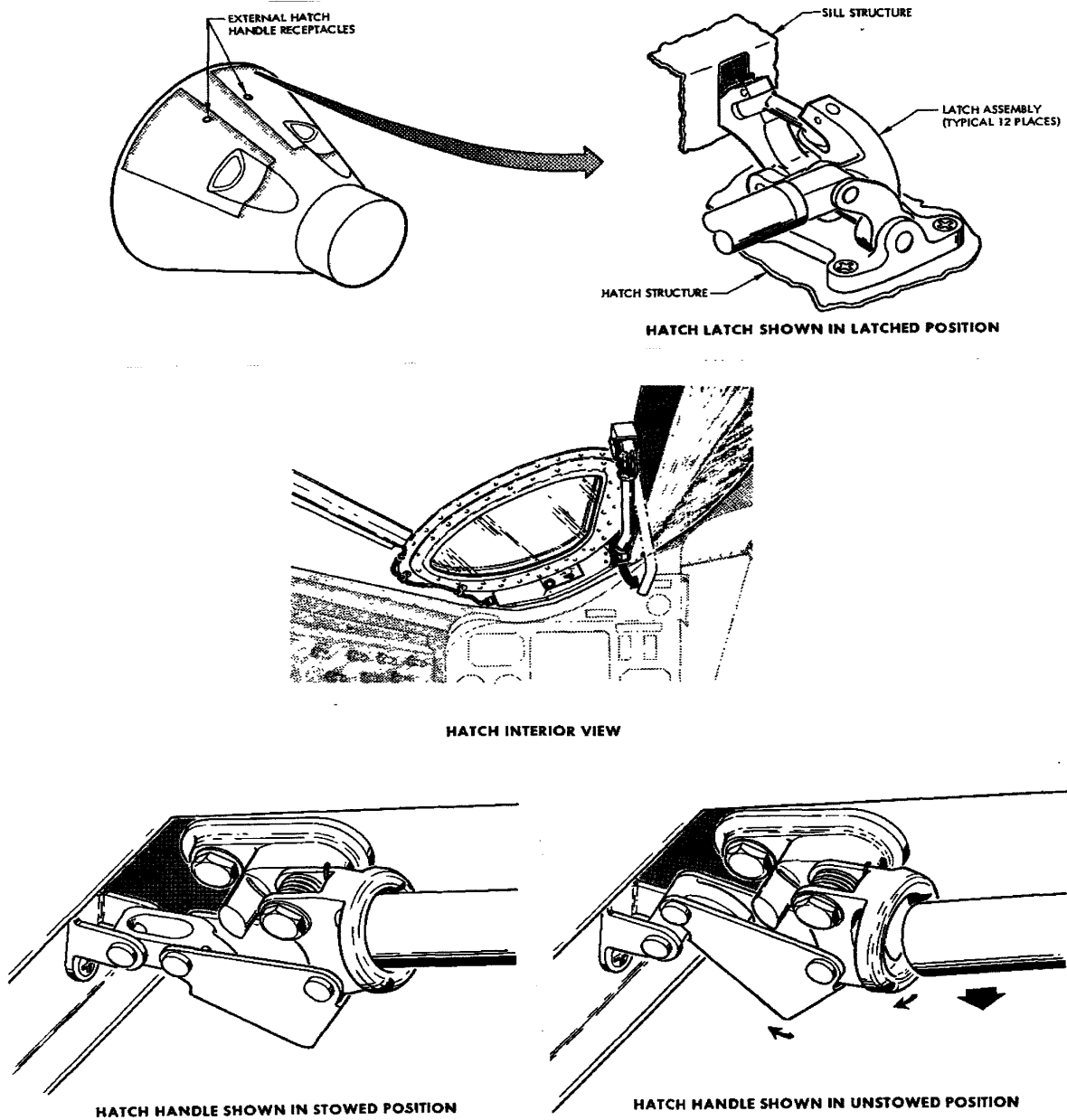


Figure 1.2.1-a Structural Hatches

SEDR 300

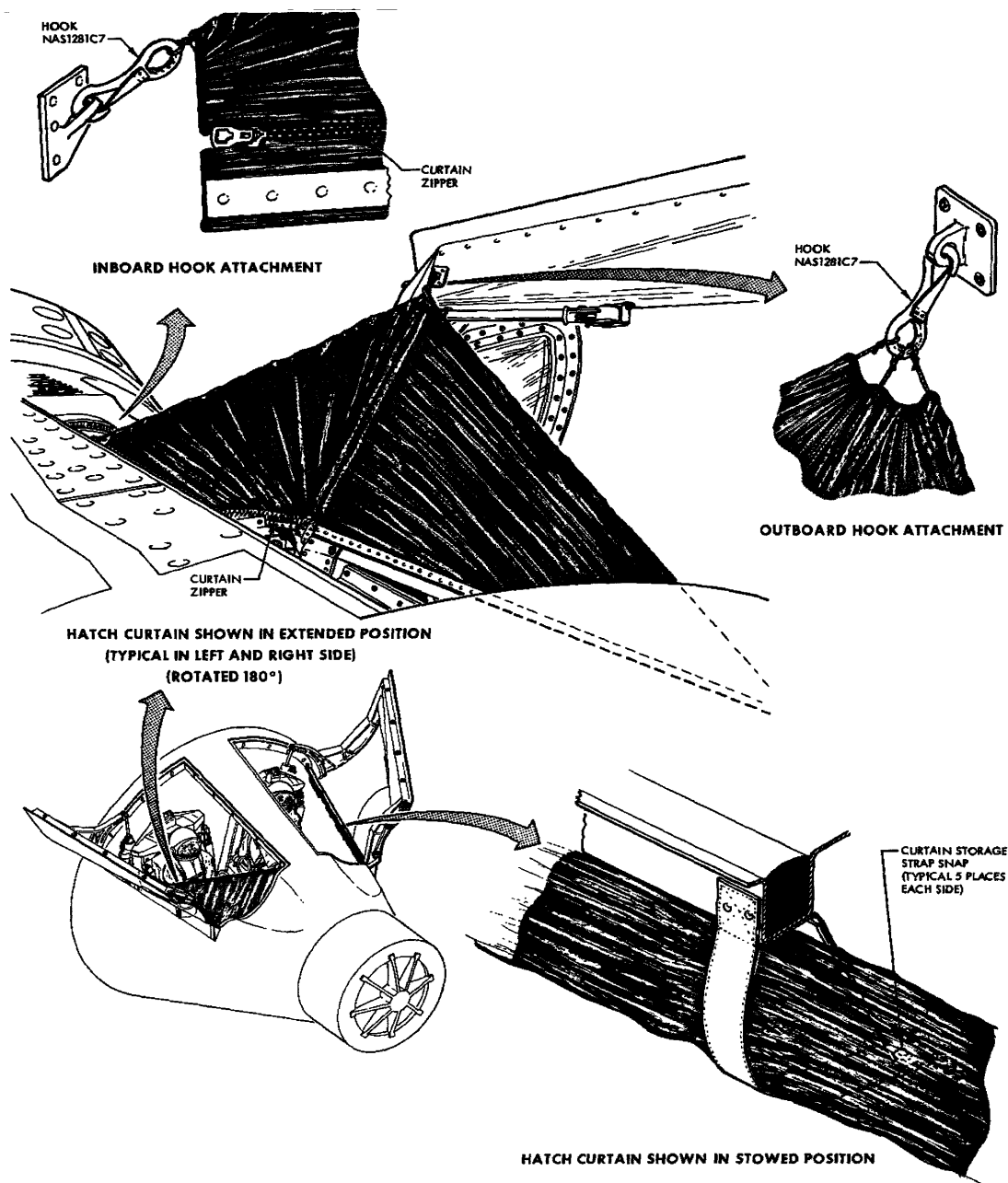


Figure 1.2.1-b Hatch Curtain

1.3 Gemini B/Manned Orbiting Lab

The United States Air Force developed a Manned Orbiting Lab (MOL) with a modified Gemini spacecraft, Gemini B (Blue). "The Gemini B was not designed to fly separately. It was launched with the crew aboard and attached to the MOL. After reaching orbit, the crew shut down the capsule systems to put them into a hibernation mode. The crew then crawled through a 0.635 m. diameter on the outward opening hatch in the heat shield, which lead to a tunnel that accessed the MOL. After 30 days of operations, the crew returned to the Gemini B, separated from the MOL, and re-entered the atmosphere. Gemini B had only 14 hours of hovering capability for autonomous operations after separation from the MOL". [Gemini B/MOL. Retrieved from the following web sites: <http://www.astronautix.com/craft/gemnibrm.htm> and <http://www.space1.com/pdf/news1096.pdf>]

Like the original Gemini spacecraft, the two (2) crew ingress/egress hatches were outward opening. The cabin atmosphere was changed to Helium-Oxygen in place of pure oxygen.

There was one (1) unmanned spacecraft flight to test the hatch in the heat shield, after which the Gemini B/MOL Program was cancelled. Figure 6 below is a photo of the heat shield hatch location, Figure 1.3-a; heat shield hatch exterior, Figure 1.3-b; and diagram contrasting the differences in the Gemini B structure with the Gemini.

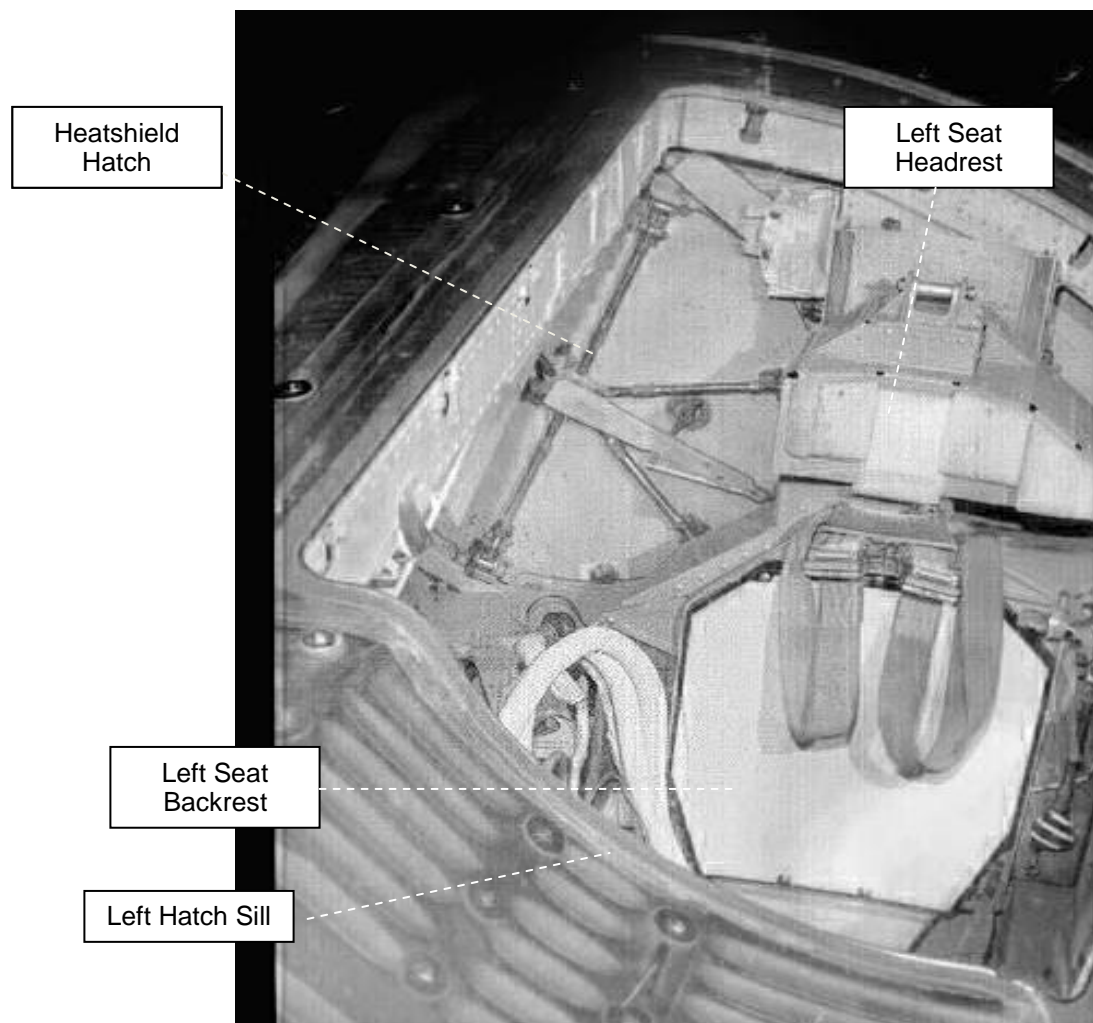


Figure 1.3-a Gemini B Heatshield Hatch

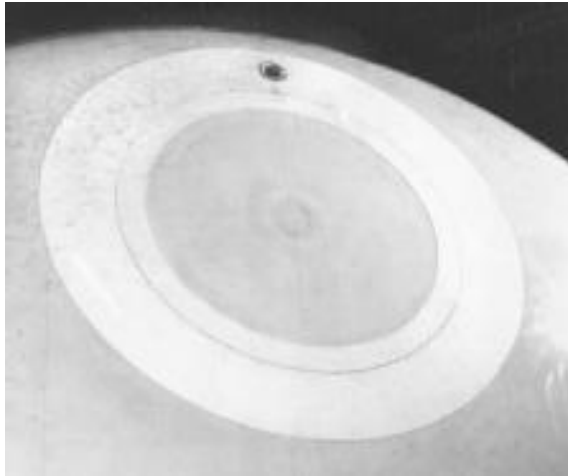


Figure 1.3-b Gemini B
Heatshield Hatch Exterior

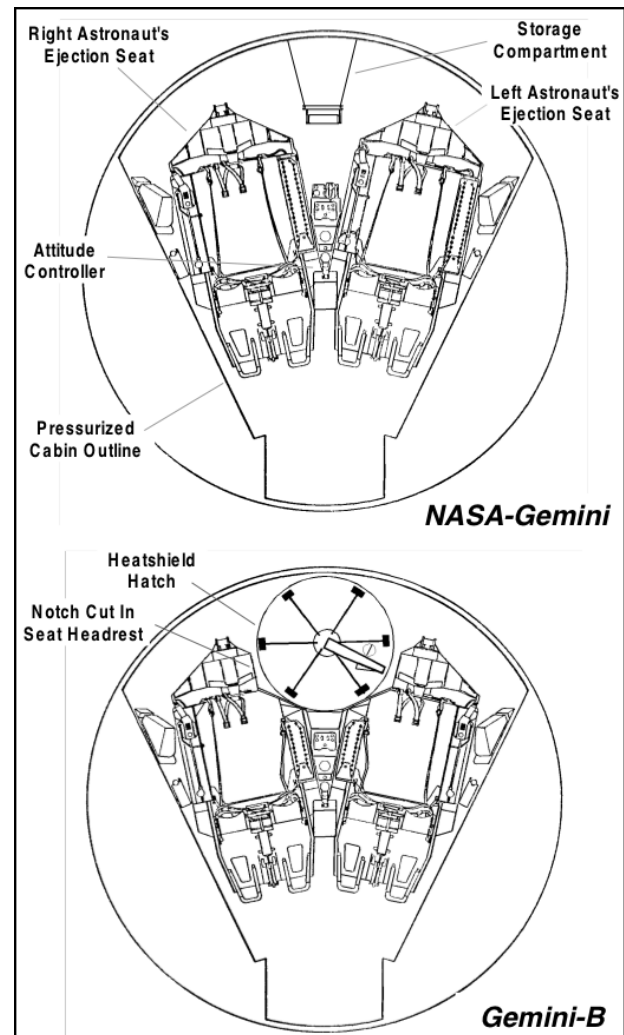


Figure 1.3-c Differences in Gemini and
Gemini-B

1.4 Apollo

Apollo spacecraft for the crew consisted of the Command and Service Module (CSM) and a Lunar Module (LM). The LM was configured with a Commander, Command Module (CM) Pilot, and LM Pilot. The Apollo Block 1 spacecraft was designed to orbit earth; the Block 2 spacecraft was designed for the Lunar Mission.

1.4.1 Block 1 CM Side Hatch

“The original hatch consisted of three doors: an inner structure (main) hatch; a middle heat shield hatch; and a lightweight outer hatch hinged to the Boost Protective Cover, which was jettisoned with the escape system shortly after launch. The inner and middle hatches had to be manually unlocked and removed to egress. The hinged outer hatch was unlocked by striking a plunger through the middle hatch that unlocked the outer hatch latches. The crew could unlock the doors, remove them, and egress in 60 to 90 seconds”. See Figure 1.4.1. [Historic Space Systems. (1996) December. Issue 2 – Apollo. Info Sheet. Retrieved from the following Web Sites: <http://www.space1.com/pdf/news1296.pdf> and http://en.wikipedia.org/wiki/Apollo_CSM]

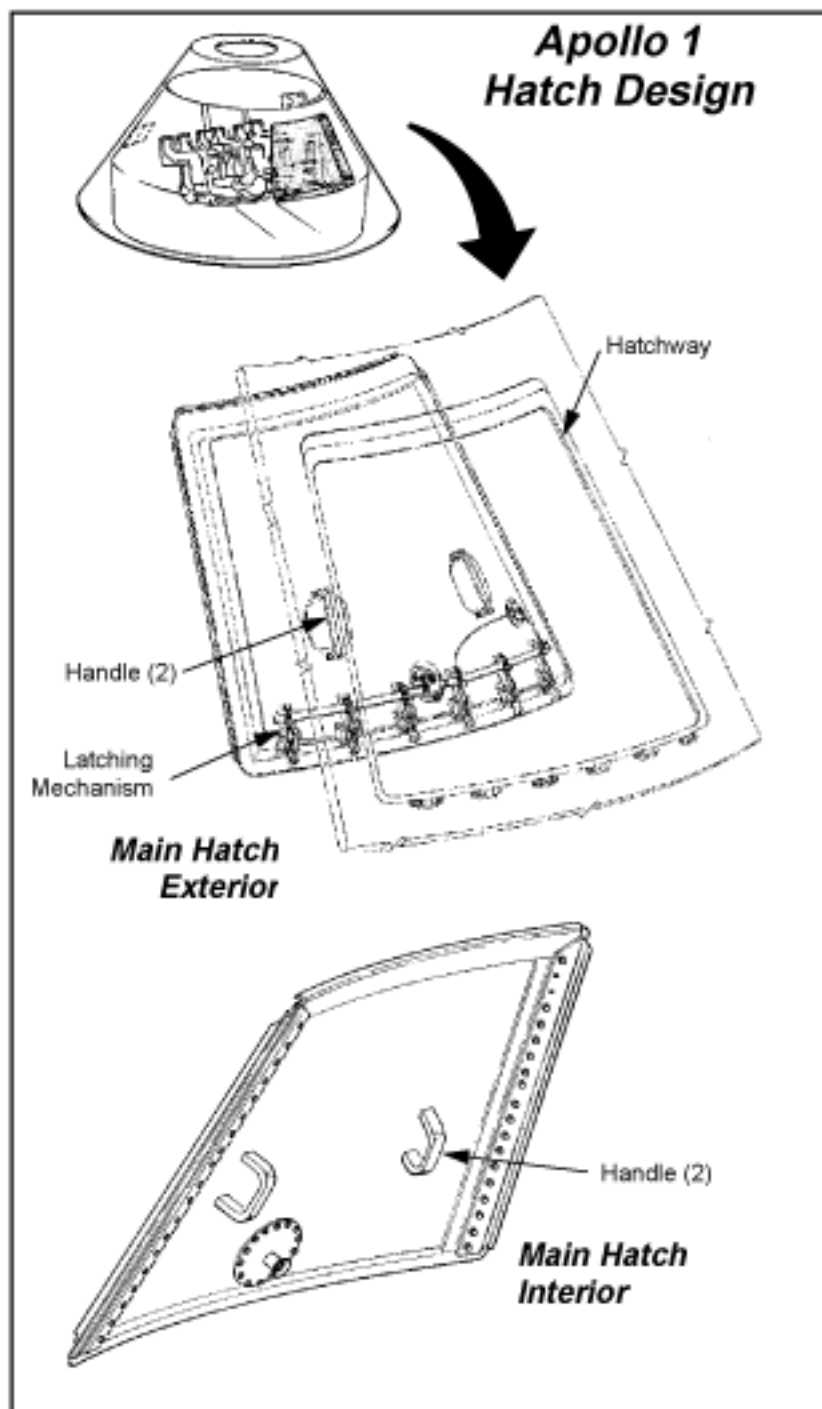


Figure 1.4.1 Block 1 CM Side Hatch

1.4.2 Block 2 CM Side Hatch

After the Apollo fire, "the crew egress requirements were drastically changed. The timeline was improved to ensure the crew could open the hatch in three (3) seconds and egress within 30 seconds. Other design requirements were dictated by schedule constraints such as: modifications to the existing spacecraft structure were to be minimal, and welding to the spacecraft structure would not be permitted. The selected design combined the inner and

middle hatches into a unified hatch. The outer hatch, part of the Boost Protective Cover, was only slightly modified. See Figure 1.4.2.

The unified hatch mounted 15 latches linked together around the hatch perimeter. The latches applied enough force from inside the hatchway to seal the hatch. A ratchet handle allowed the crew to open or close the latches in five (5) strokes of the handle. The handle also triggered a striker plunger to unlock the outer hatch latches while the Boost Protective Cover was still attached.

A counterbalance improved the opening time in emergency situations. Once the latches were unlocked, a cylinder was pressurized with gaseous nitrogen that activated a piston to force the combined 350 pound hatch open, and lock it into position. The total weight added by the new design was 253 pounds". *Historic Space Systems*. (1996) December. Issue 2 – Apollo. Info Sheet. Retrieved from the following Web Sites: <http://www.space1.com/pdf/news1296.pdf> and http://en.wikipedia.org/wiki/Apollo_CSM

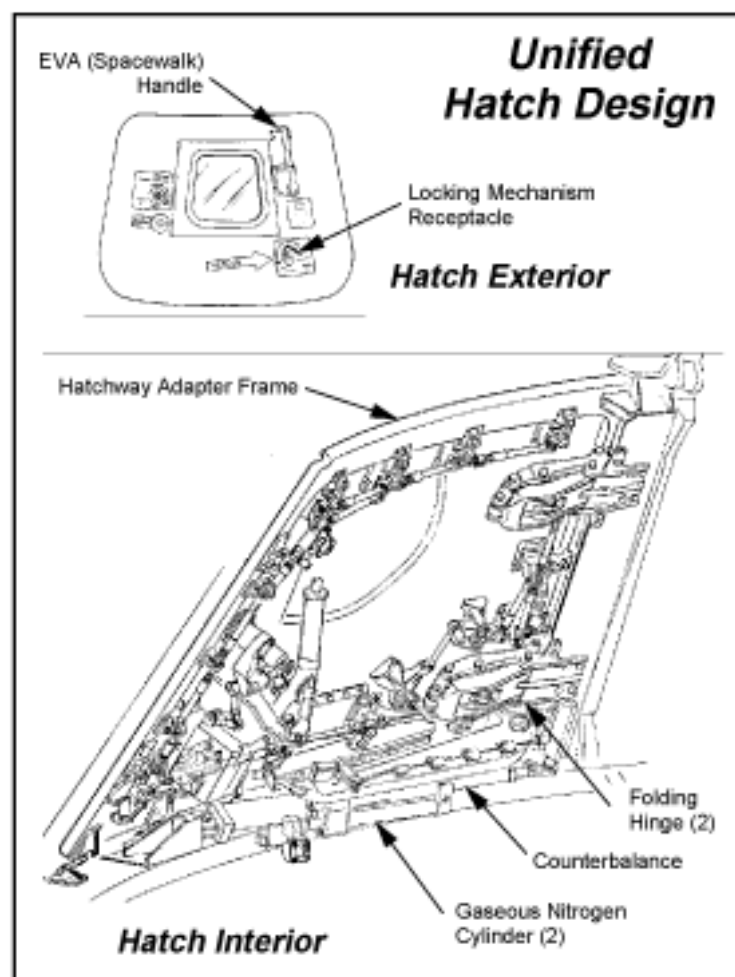


Figure 1.4.2 Unified Hatch

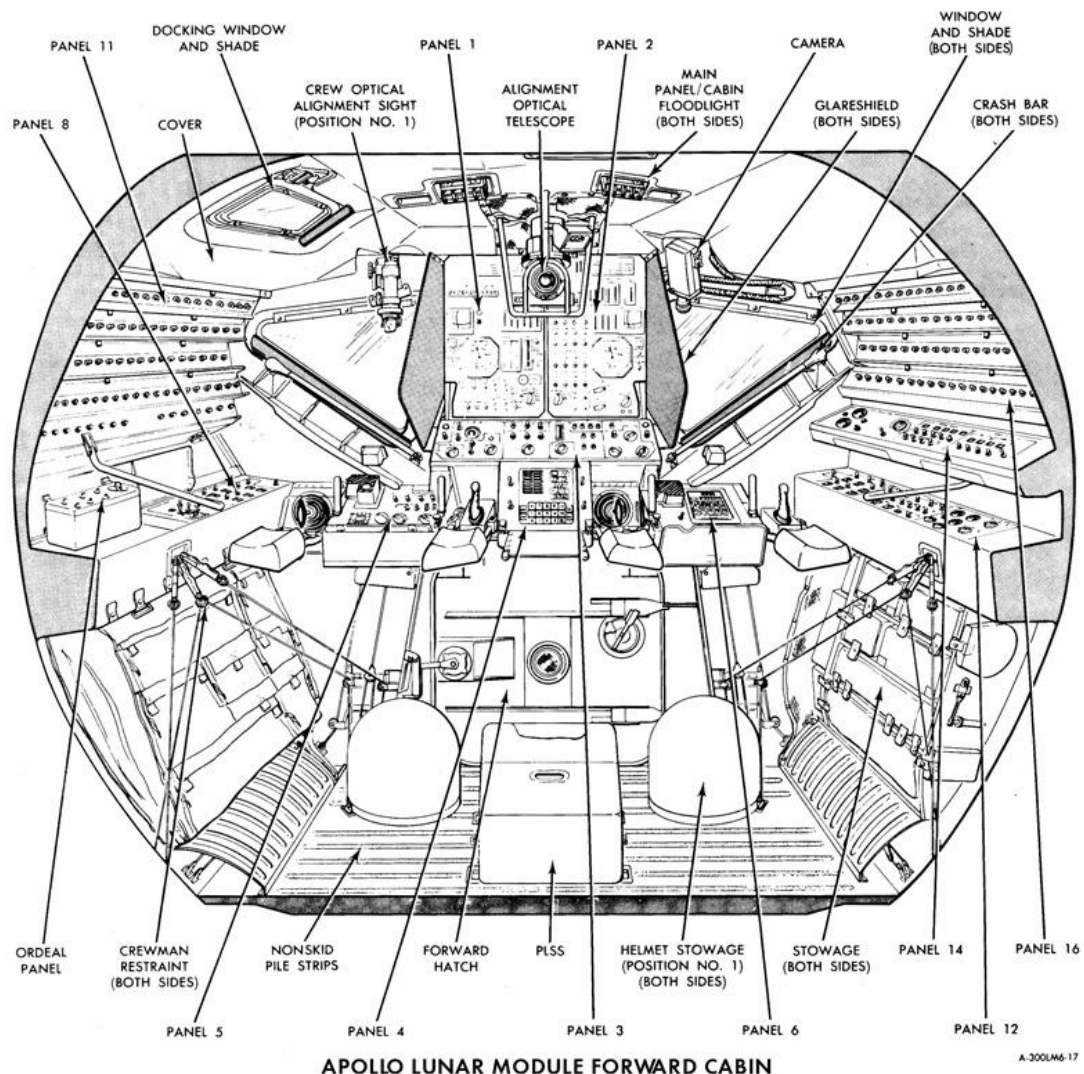
1.4.3 Block 2 CM Docking/Transfer Hatch

"The forward docking hatch was mounted at the top of the docking tunnel. It was 30 inches (760 mm) in diameter and weighed 80 pounds (36kg). It was constructed from two (2) machined rings that were weld-joined to a brazed honeycomb panel. The exterior side was covered with

0.5 inches (12.70mm) of insulation and a layer of aluminum foil. It was latched in six (6) places and operated by a pump handle. At the center was a pressure equalization valve, used to equalize the pressure in the tunnel and lunar module before the hatch was removed". *Historic Space Systems*. (1996) December. Issue 2 – Apollo. Info Sheet. Retrieved from the following Web Sites: <http://www.space1.com/pdf/news1296.pdf> and http://en.wikipedia.org/wiki/Apollo_CSM

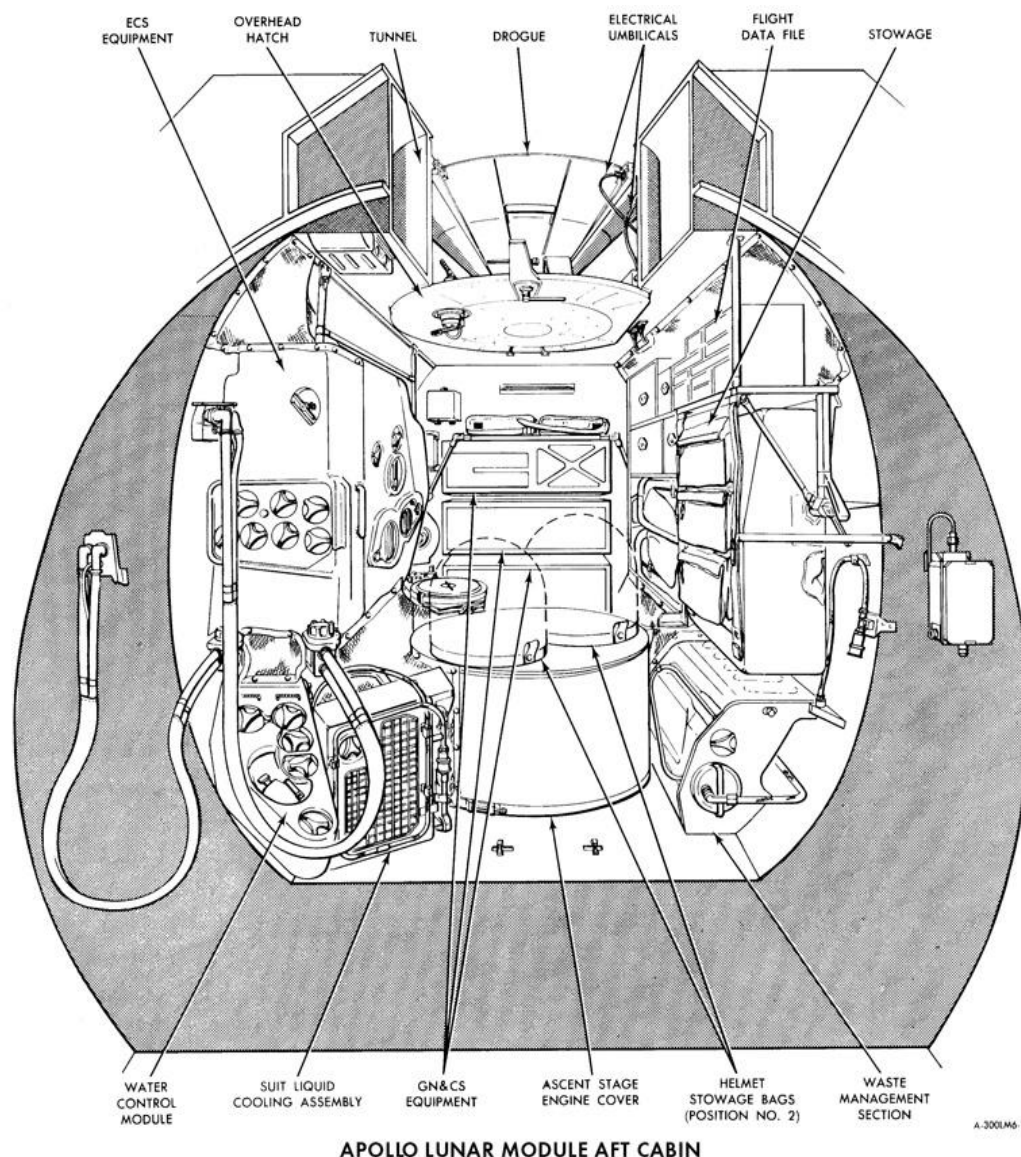
1.4.4 Lunar Module

The LM forward hatch opened inward to the right, this design permitted the Commander to exit first. The overhead hatch opened inward to facilitate the transfer to and from the CM. Both the LM forward hatch and the overhead hatch were pressure sealing. See drawing of LM Forward Cabin, Figure 1.4.4-a, and drawing of LM aft cabin, Figure 1.4.4-b. [Reference 5]



Ref Apollo Operations Handbook LMA790-3-LM5 and Subsequent, 15 June 1969 - Scan by Historic Space Systems at space1.com

Figure 1.4.4-a

**Figure 1.4.4-b**

1.5 Skylab

The Skylab Program was the first U.S. space station. The Apollo CSM was modified for transporting the crew to and from the Skylab and the Saturn V third stage; the S-IVB was changed to become the Orbital Workshop. Skylab also contained four (4) new compartments: the Airlock Module; the Apollo Telescope Mount, the Multiple Docking Adapter (MDA), and the Saturn Instrument Unit. See Figure 1.5. [Reference 6]

1.5.1 Skylab CM

The Skylab CM crew hatches (side and docking/transfer) were the same as the Apollo Block 2 CM.

1.5.2 Skylab

The EVA hatch in the Airlock Module was a hatch from the Gemini Program and was opened outward. The crew transfer hatches in the Orbital Workshop, MDA, and the Airlock, were all inward opening and pressure sealing hatches.



Figure 1.5

Pilot Joe Kerwin shown in the hatch between the Multiple Docking Adapter and the Apollo spacecraft.

1.6 Apollo Soyuz Test Project (ASTP)

The ASTP involved the U.S. and Russia in a joint mission to dock the Apollo CSM with the Russian Soyuz to erect a compatible docking system.

The crew atmosphere was different for each of the vehicles, which required a module to allow the crew to transfer between them. The crew atmosphere for Apollo was 5 psi pure oxygen, and for Soyuz the cabin atmosphere was air at a pressure of one (1) atmosphere. The U.S. Docking Module was designed and developed to provide for the crew transfer.

1.6.1 ASTP CM

The ASTP CM crew hatches (side and docking/transfer) were the same as the Apollo Block 2 CM.

1.6.2 ASTP Docking Module

The Docking Module (DM) contained crew hatches for docking and crew transfer (CSM/DM docking and DM/Soyuz docking). The modified CM forward hatch was used for the DM crew transfer hatches. Both DM hatches opened inward and were pressure sealing. See drawings of DM, Figures 1.6.2-a, and 1.6.2-b. [Reference 7]

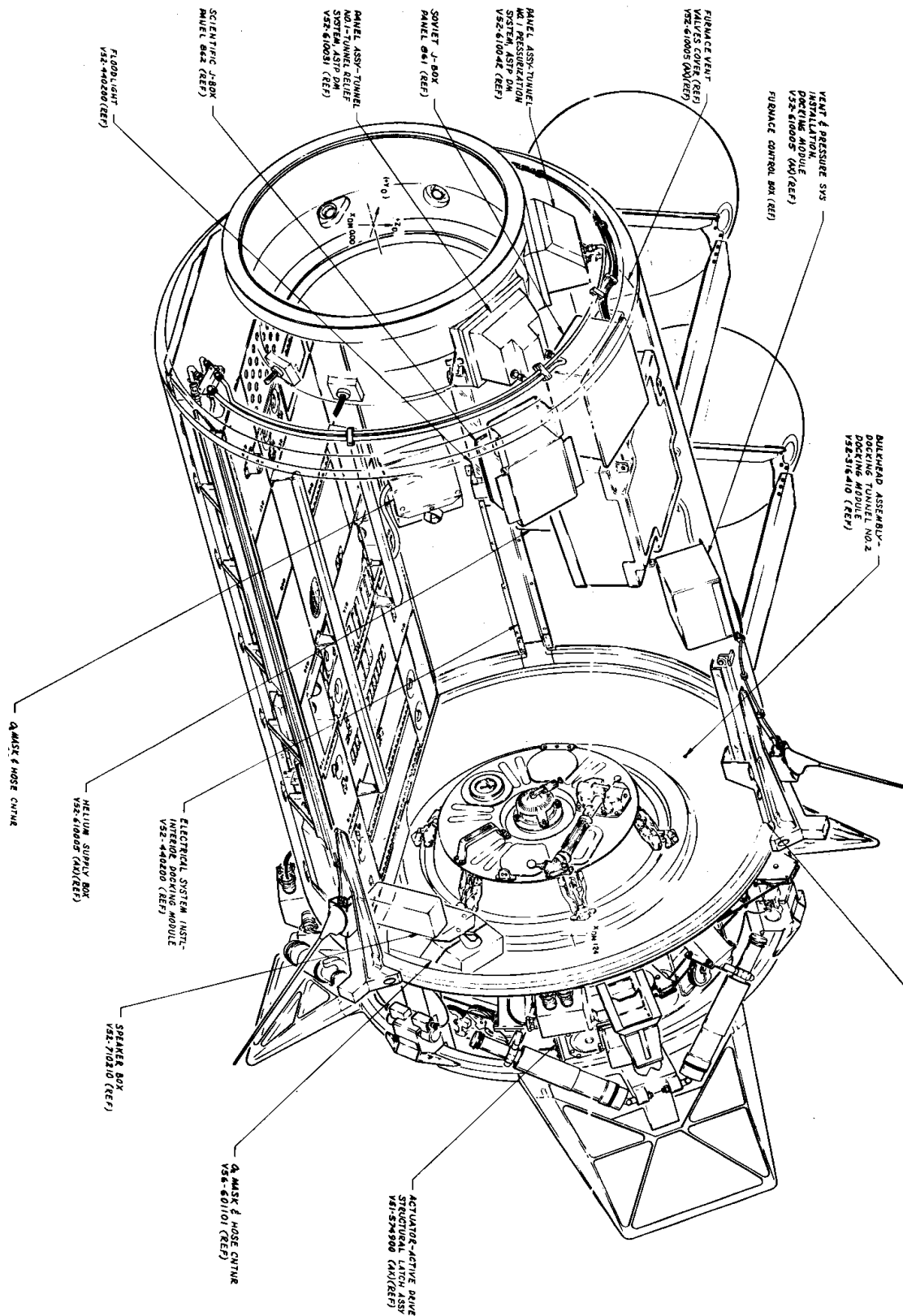


Figure 1.6.2-a ASTP Docking Module



1.7 Space Shuttle Orbiter

1.7.1 Orbiter Side Hatch

The side hatch for crew ingress/egress opened outward and was equipped with pyrotechnic jettison to enable crew egress in an emergency.

1.7.2 Side Hatch Structure

"The side hatch in the middeck is used for normal crew ingress/egress and may be operated from within the crew cabin middeck or externally. It is attached to the crew cabin tunnel by hinges, a torque tube, and support fittings. The hatch opens outwardly 90° down with the orbiter horizontal or 90° sideways with the orbiter vertical. It is 40 inches in diameter and has a 10-inch clear-view window in the center of the hatch.

The side hatch has a pressure seal that is compressed by the side hatch latch mechanisms when the hatch is locked closed. A thermal barrier is constructed of Inconel wire mesh spring. A ceramic fiber braided sleeve is installed between the reusable surface insulation tiles on the forward fuselage and the side hatch. The total weight of the side hatch is 294 pounds. See drawing of Side Hatch Assembly below", Figure 1.7.2. [JSC-28922, Shuttle OPS, MMACS, Vol. VI. Rev. A. PCN-4. Dated 4-1-07]

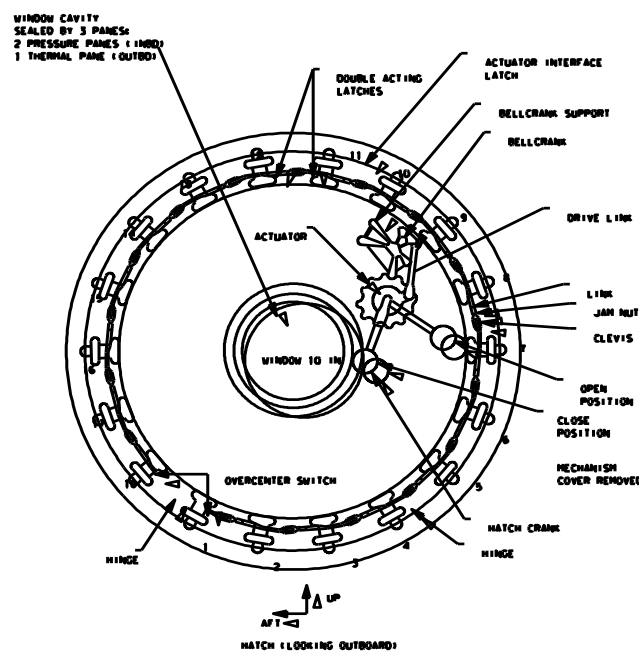


Figure 1.7.2 Side Hatch Assembly

1.7.3 External Airlock Hatches (Airlock, EVA, and Docking)

"Three (3) pressure-sealing hatches are mounted on the airlock. They are designated as an inner hatch, an EV hatch, and a docking hatch. The inner hatch is located on the exterior of the external airlock opening into the middeck. The inner hatch isolates the airlock from the crew cabin. The inner hatch is hinged to be pulled first into the middeck and rotated down until it rests with the low-pressure (outer) side facing the airlock floor. The hatch has a hold-open hook that snaps into place over a flange when the hatch is fully open". See drawings of Typical EV, B Hatch Assembly, Figure 1.7.3-a, and Typical Docking, D Hatch Assembly, Figure 1.7.3-b below.

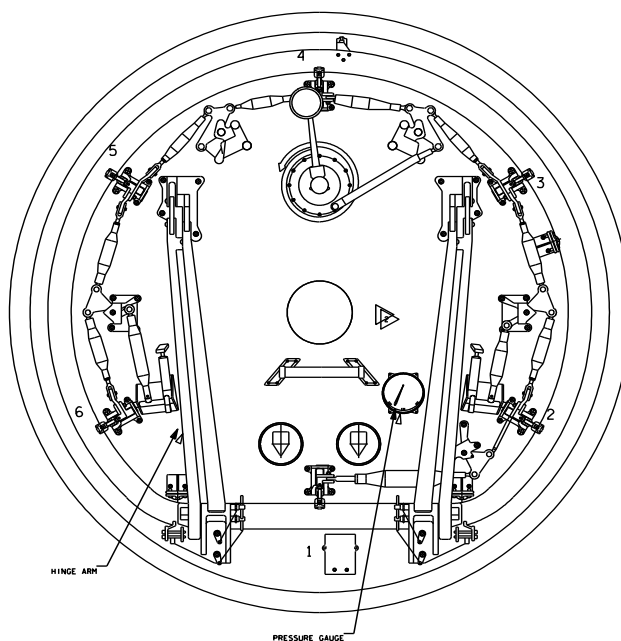


Figure 1.7.3-a Typical EV, B Hatch Assembly

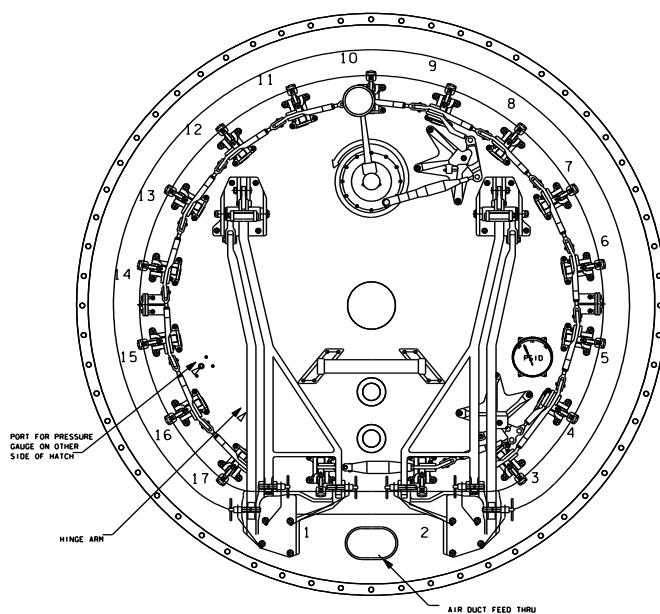


Figure 1.7.3-b Typical Docking, D Hatch Assembly

“The EV hatch isolates the airlock from the unpressurized payload bay when closed and permits the EVA crewmembers to exit from the airlock to the payload bay when open. The EV hatch of the external airlock opens in the same manner as the inner hatch. The external airlock’s third hatch is an additional upper, outer hatch that is used for docking operations. The docking hatch, located on the top of the external airlock (toward the payload bay doors), is hinged to be pulled

into the external airlock and then rotated until the low pressure side rests against the airlock wall facing toward the nose of the orbiter. Each hatch has **interconnected latches with gearbox and actuator**, a window, a hinge mechanism with hold-open device, a differential pressure gauge on each side, and two equalization valves. The external airlock hatches also have hold-open protection and deployable struts for support against the airlock structure. External airlock repressurization is controlled from the middeck or inside the external airlock. It is performed by equalizing the external; airlock and cabin pressure with airlock-hatch mounted equalization valves on the inner hatch. Depressurization of the external airlock is controlled from inside the external airlock. It is depressurized by venting the external airlock pressure overboard. The three D-shaped airlock hatches are installed to open toward the primary pressure source, the orbiter crew cabin, to achieve pressure-assist sealing when closed. Each hatch opening is 40 inches in diameter, yet with one side being flat, the minimum dimension is 36 inches”.

“Each external airlock hatch has dual pressure seals to maintain the external airlock’s pressure integrity. One seal is mounted on the external airlock hatch and the other on the external airlock structure. A leak check quick disconnect is installed between the hatch and the airlock pressure seals to verify hatch pressure integrity before flight. Each airlock hatch has the following design characteristics: 1) capable of being fully locked/ unlocked from either side, 2) designed for 2000 open/close cycles, 3) one-handed operation by astronaut in pressure suit, 4) capable of opening against 0.2 psi maximum, 5) latches capable of withstanding 20 g’s in the +X direction, and 6) actuator handle load of 30 pounds maximum”.

“The gearbox with latch mechanisms on each hatch allows the flight crew to open or close the hatch during transfers and EVA operations. The gearbox and the latches are mounted on the low-pressure side of each hatch, with a gearbox handle installed on both sides to permit operation from either side of the hatch. Some of the latches on each hatch are double-acting with cam surfaces that force the sealing surfaces apart when the latches are opened, thereby acting as crew-assist devices. To latch or unlatch the hatch, the gearbox handle must be rotated 440°. The hatch actuator/gearbox is used to provide the mechanical advantage to open and close the latches. The hatch actuator lock lever requires a force of 8 to 10 pounds through an angle of 180° to unlatch the actuator. A minimum rotation of 440° with a maximum force of 30 pounds applied to the actuator handle is required to operate the latches to their fully unlatched positions. The hinge mechanism for each hatch permits a minimum opening sweep into the airlock or the crew cabin middeck”. [JSC-28922, Shuttle OPS, MMACS, Vol. VI. Rev. A. PCN-4. Dated 4-1-07]

During the STS-80 mission in November 1996, a loose screw in the gearbox was the cause for the jammed hatch that cancelled two (2) EVAs on Columbia, Figure 1.7.3-c. [Reference 9]

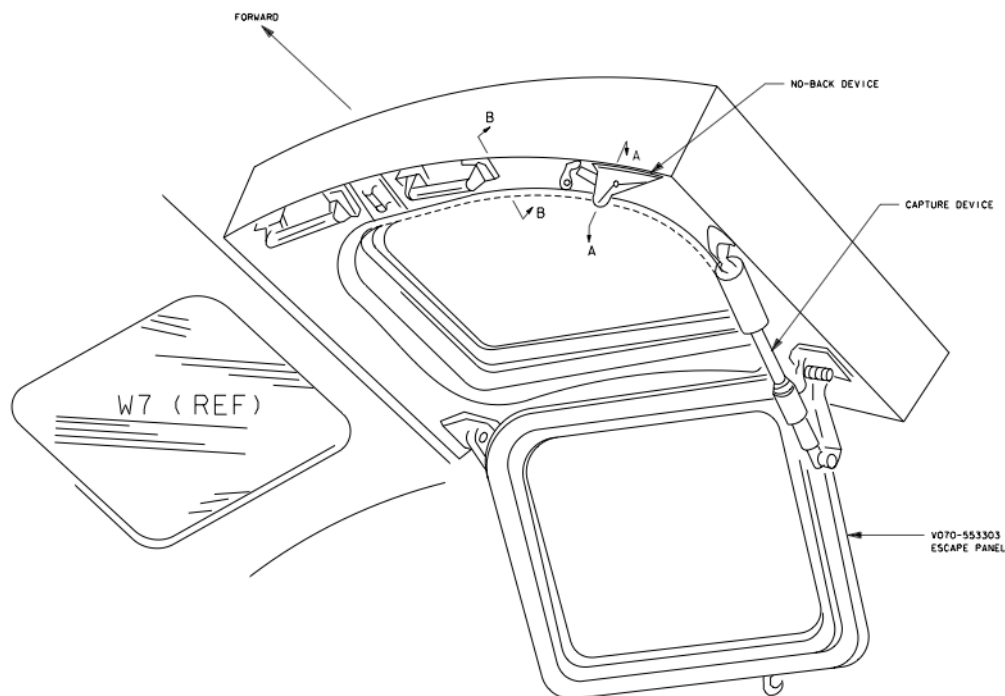


Figure 1.7.3-c
Jammed hatch from loose screw

1.7.4 Overhead Escape Panel

“The port side flight deck overhead window (Window 8) provides the flight crew with a secondary emergency egress route, in the event that egress through the side hatch is not possible. The overhead window consists of three panes of glass, two panes are attached to the crew compartment and one is attached to the upper forward fuselage. The overhead window jettison system consists primarily of expanding tube assemblies, mild detonating fuses, frangible bolts, and associated initiators. Pulling the ring handle located forward of the flight deck center console (C3) activates the overhead window jettison system. When initiated, the outer pane is jettisoned upward and aft. A time delay in the pyrotechnic firing circuit delays the initiation of the opening of the inner pane 0.3 seconds after the outer pane is jettisoned. The inner window pane rotates downward and aft into the crew compartment aft flight deck on hinges located at the aft portion of the window frame. A capture device attenuates the opening rate and holds the window in position. This overhead window jettison system can also be initiated by ground personnel from the outside of the orbiter on the starboard side of the forward fuselage.

Crewmembers use the MS2 seat (Seat 4) to climb up through the window. Seven emergency ground descent devices (Sky Genies) are stowed on the overhead aft flight deck outboard of each overhead window, one for each flight crewmember. The emergency ground descent device enables crewmembers to lower themselves to the ground over the starboard side of the orbiter. See drawing of Overhead Escape Panel”, Figure 1.7.4. [JSC-11174 Section 18-Escape/Crew Systems. Dwg.18.1 Escape Panel]



INNER WINDOW OPERATION

- WHEN CABIN TO ATMOSPHERE $\Delta P \leq 0.25$ PSID, THE WINDOW OPENS AND THE CAPTURE DEVICE HOLDS THE WINDOW FULL OPEN FOR EGRESS.
- WHEN CABIN TO ATMOSPHERE $\Delta P > 0.25$ PSID, AND ≤ 0.44 PSID, THE WINDOW OPENS AND THE NO-BACK DEVICE ENGAGES TO PREVENT SUBSEQUENT WINDOW CLOSING DURING CABIN PRESSURE EQUALIZATION.
- WHEN CABIN TO ATMOSPHERE $\Delta P > 0.44$ PSID, THE WINDOW WILL NOT OPEN FAR ENOUGH TO ENGAGE THE NO-BACK DEVICE. THE PRYBAR MUST BE USED TO PRY THE WINDOW OPEN TO ENGAGE THE NO-BACK DEVICE AND ALLOW CABIN PRESSURE EQUALIZATION.
- AFTER CABIN PRESSURE EQUALIZATION, THE WINDOW WEIGHT (150 LB) WILL OPEN THE WINDOW.

Figure 1.7.4
Overhead Escape Panel

1.8 International Space Station (ISS)

1.8.1 Russian Segment

The Russian segment of the ISS consists of the Functional Cargo Block (FGB) also known as Zarya; it is the first ISS Module launched and developed by the Khrunichev Space Corporation (KhSC). The Russian Service Module (SM) named Zvezda was the first ISS module containing crew equipment and accommodations to enable working and living on the ISS; it was developed by the Rocket Space Corporation Energia (RSCE). The Russian segment also has the Docking Compartment and Airlock named Pirs, as shown in Figure 1.8.1. [Reference 11]

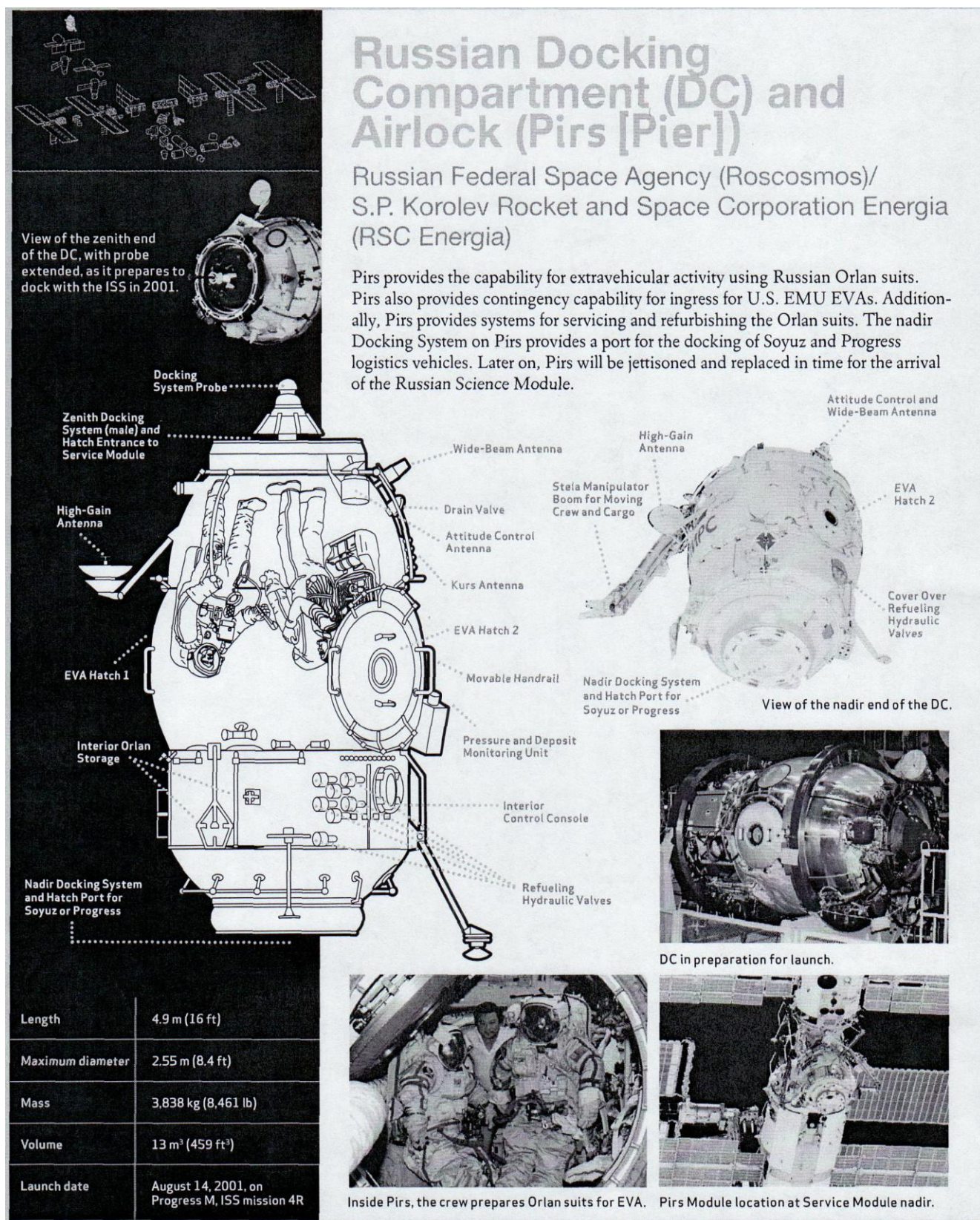


Figure 1.8.1 Russian Docking Compartment and Pirs

The Modules for future launch are the Mini-Research Module 2 (MRM 2) to be carried on a Progress flight and docked to the Russian Service Module, Zvezda; the MRM 2 is very similar to Pirs. The Mini-Research Module 1 (MRM 1) is a Docking Cargo Module, built from the pressurized hull of the cancelled Solar Power Platform, and it is docked to the FGB (Zarya), with two docking ports. The final module to be launched is the Multipurpose Laboratory Module (MLM) it is the modified KhSC built FGB 2 and will also be docked to the Russian Service Module, Zvezda. The MLM will be used for experiments, docking, and cargo. All of the Russian Segment docking, transfer and EVA hatches are inward opening and pressure sealed.

The hatch device requirements and description identified for the FGB. "Requirements for the FGB hatch device from the *Specification of Technical Requirement for the FGB*, [SSP 50128]:

Paragraph 3.2.4.4. The hatch and seals must be accessible for inspection, maintenance, and repair by crew members.

Paragraph 3.3.6.1.20.2. The design must permit isolation of FGB pressurized compartments within 3 minutes, including the closing of hatches.

Paragraph 3.3.6.1.20.8. The hatch design must provide for hatch opening and closing from either side by a single crew member."

"The hatch device consists of the hatch cover with a double-barrier rubber seal to ensure reliable sealing, a sealing mechanism, and telemetering microswitches to signal the closed position of the hatch device."

"The main characteristic of the hatch device are the hatch inside diameter at 800mm; the hatch cover opening angle at 105 degrees; sealing mechanism opening time at 2 seconds; cover withdrawal time at 5 seconds; weight at 25kg; and operating life cycle at 300 cycles."

"To ensure reliable operation, when the hatch is open the rubber seals are covered by a protective guard ring. The hatch cover can be opened and closed from either side by a single crew member."

"The hatch cover design, the crosspieces, the sealing mechanism, and the microswitches are prototypes of analogous assemblies of the internal hatch device of the Kvant-2 module."

"The design of the double-barrier rubber seal is analogous to the design of the seal of the exit hatch of the Kvant-2 module, whose operation has been tested in space during many EVA's by crew members." [FGB-PB-0481. KhSC Salyut Design Bureau. ISS FGB Energy Block. EN-01 Design Description Document. Volume 5. (1997) June 10]

1.8.2 U.S. Segment

The first U.S. ISS Module launched with the attached Pressurized Mating Adapter (PMA) was the Node 1, named Unity; it was equipped with the and was docked to the FGB (Zarya). The U. S. Lab named Destiny, expanded the crew operating work space and was berthed to Unity. The U.S./Joint Airlock also known as Quest (Figure 1.8.2-a), was berthed to Unity. The U.S. ISS Module Node 2 was called Harmony and was berthed to Destiny. [Reference 12]

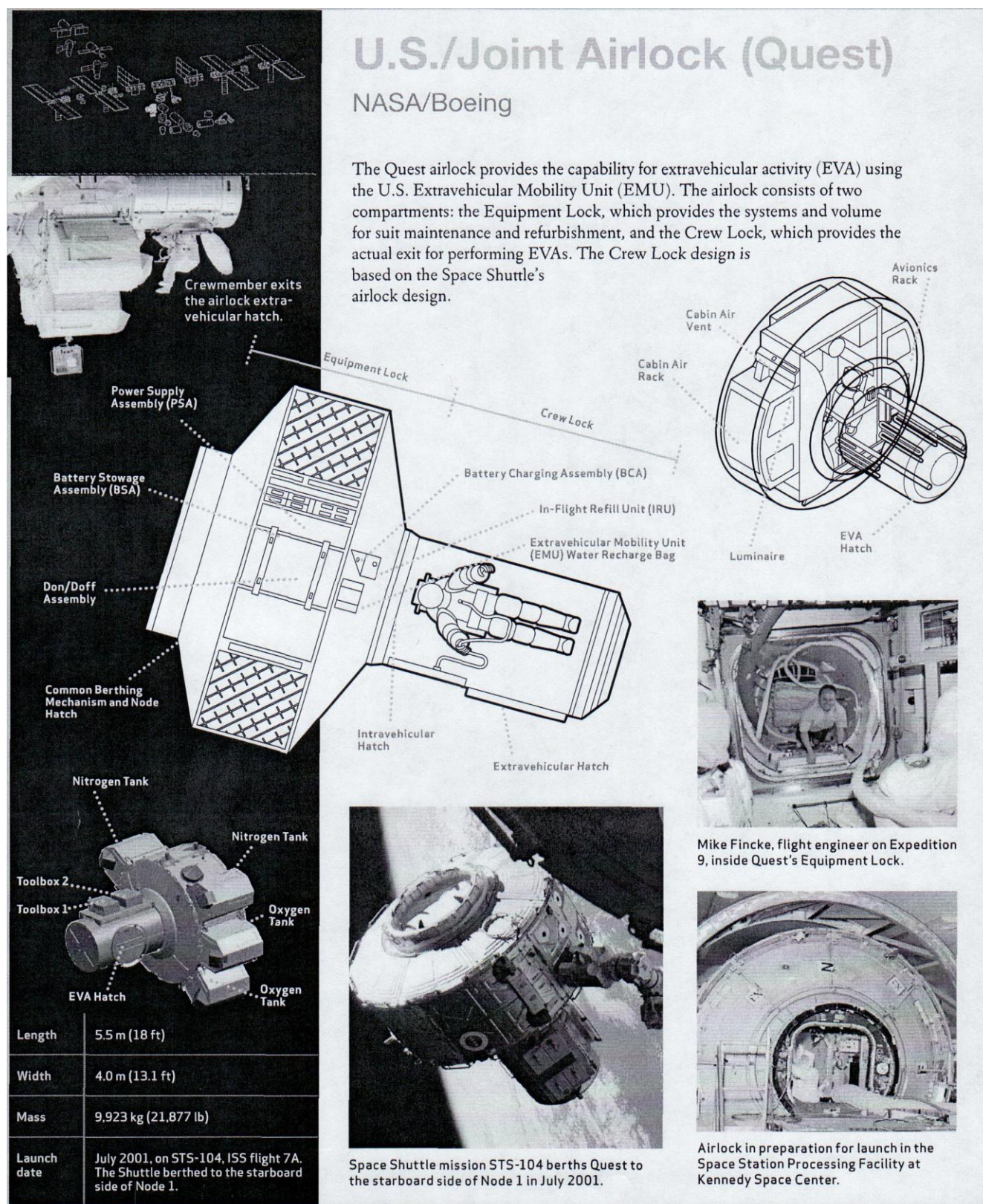


Figure 1.8.2-a US/Joint Airlock (Quest)

The European Laboratory developed by the European Space Agency (ESA) and named Columbus is considered a part of the U.S. Segment and was developed by the International Partners it is shown in Figure 1.8.2-c. [Reference 13] It was launched on the Space Shuttle and berthed to Harmony.

The Japanese Experiment Logistics Module developed by Japan Aerospace Exploration Agency (JAXA) called Kibo, included in the U.S. Segment was launched on the Space Shuttle and was berthed to Harmony. The Japanese Kibo Pressurized Module (Figure 1.8.2-d) [Reference 14] was launched on the Space Shuttle and temporarily berthed to Node 2 (Harmony); its permanent home is on the Japanese Lab, Kibo.

A future scheduled launch is planned for Node 3 that NASA has named Tranquility, it will have the Cupola attached, and be berthed to Unity. The final U.S. segment module to be launched will be the Permanent Logistics Module (PLM) which is planned to be the European Multi-Purpose Logistics Module (MPLM) named Raffaello.

All of the U.S. Segment berthing and transfer hatches are referred to as the U.S. Orbital Segment (USOS) Standard Hatch and are inward opening and pressure sealed. See Figure 1.8.2.-a, for a drawing of the Outer Hatch Assembly and Figure 1.8.2-b for a drawing of the Inner Hatch Assembly. [Reference 12]

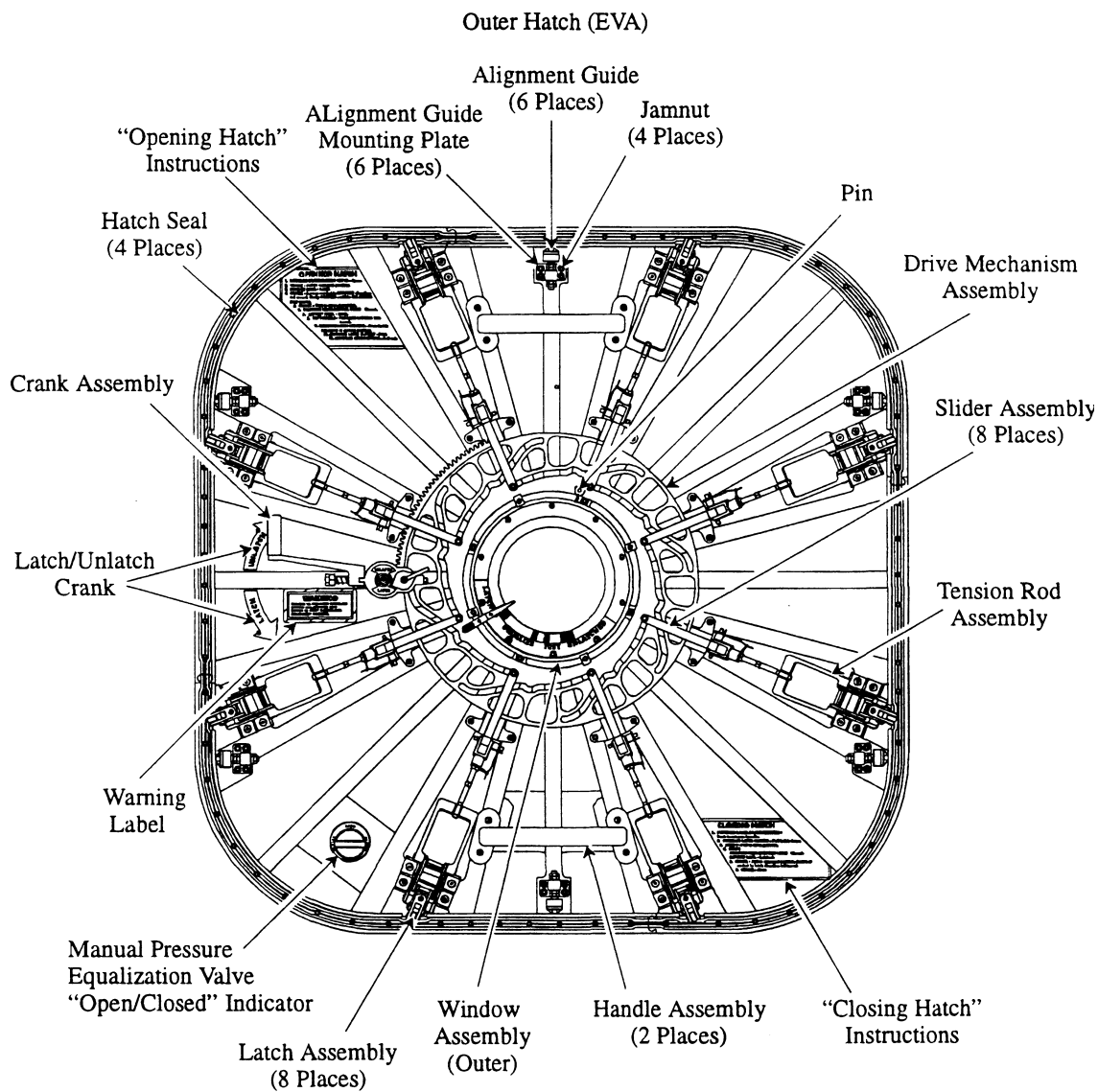


Figure 1.8.2-a Outer Hatch Assembly

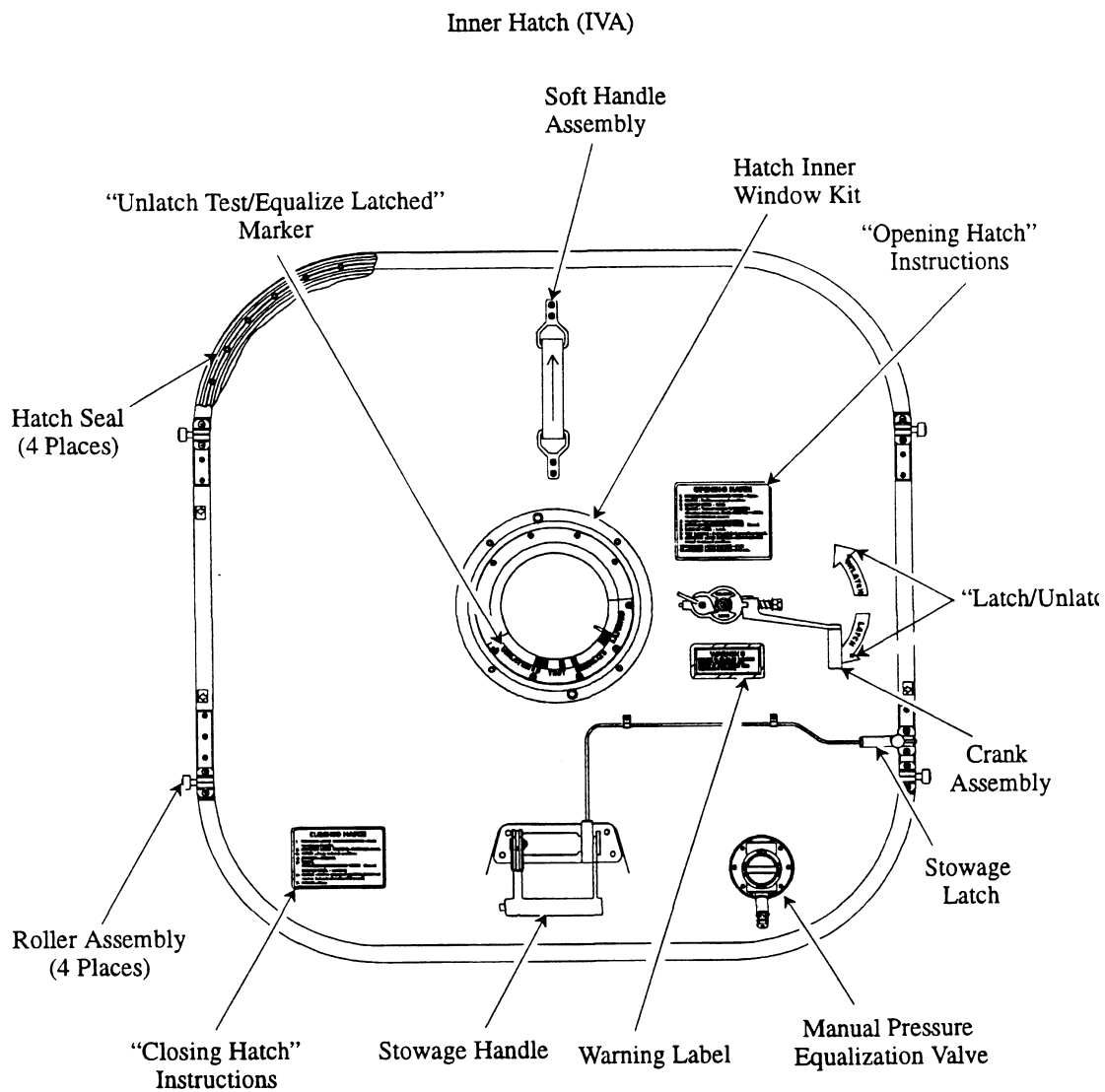


Figure 1.8.2-b Inner Hatch Assembly



S122E008911

Figure 1.8.2-c
Columbus Module (Interior)



Figure 1.8.2-d
Kibo Pressurized Module

1.8.3 Automated Transfer Vehicle (ATV) European

The ATV, Figure 1.8.3, is an ISS logistics and resupply vehicle manufactured by the European Space Agency (ESA). It is launched on the European Arian, and automatically docks to the Russian Service Module, (Zvezda) aft docking port. The docking and transfer hatch is the same as the Russian docking and transfer hatch, using the same hatch tool for opening and closing. The hatch is inward opening and pressure sealed. [Reference 15]



Figure 1.8.3 ATV

1.8.4 H-2 Transfer Vehicle (HTV) Japanese Cargo Vehicle

The HTV is launched on the Japanese H-2B [rocket] and is berthed to the U.S. Harmony Module. The HTV uses the USOS Standard berthing and crew transfer hatch, it is inward opening and pressure sealing. See Figure 1.8.4. [Reference 16]

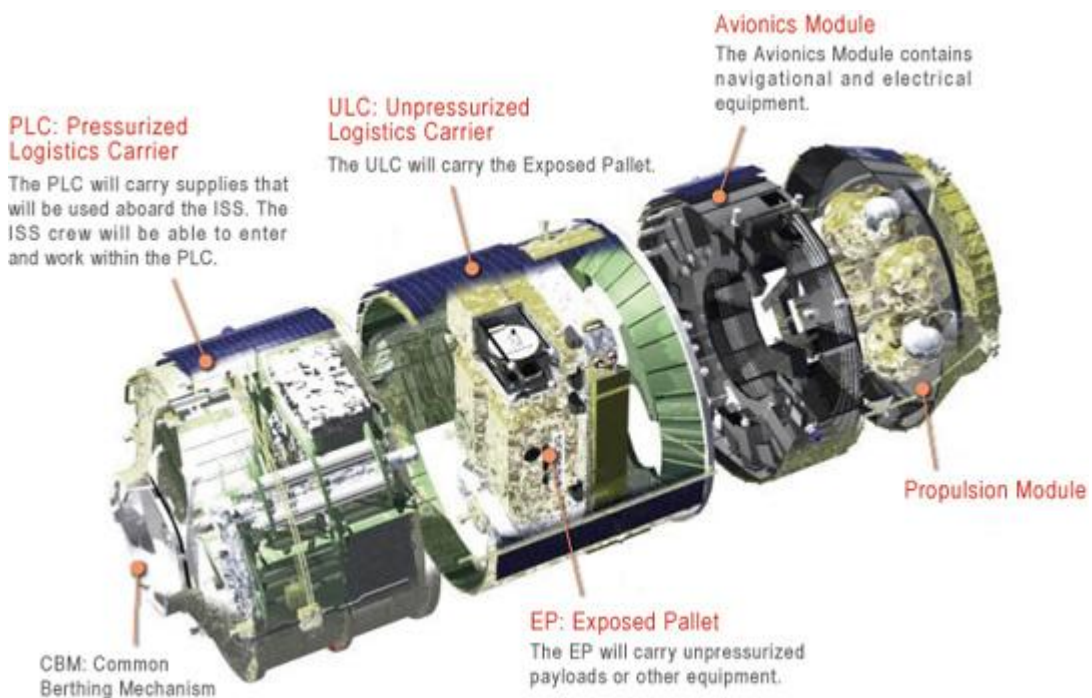


Figure 1.8.4 HTV

2.0 History of Russian Spacecraft Crew Hatches

2.1 Vostok

The Vostok was the first spacecraft to launch a man to orbit. It had one entry hatch that was pyrotechnically jettisoned when the crewman ejected before landing. See Figure 2.1 below. [Reference 17]



Figure 2.1 Vostok

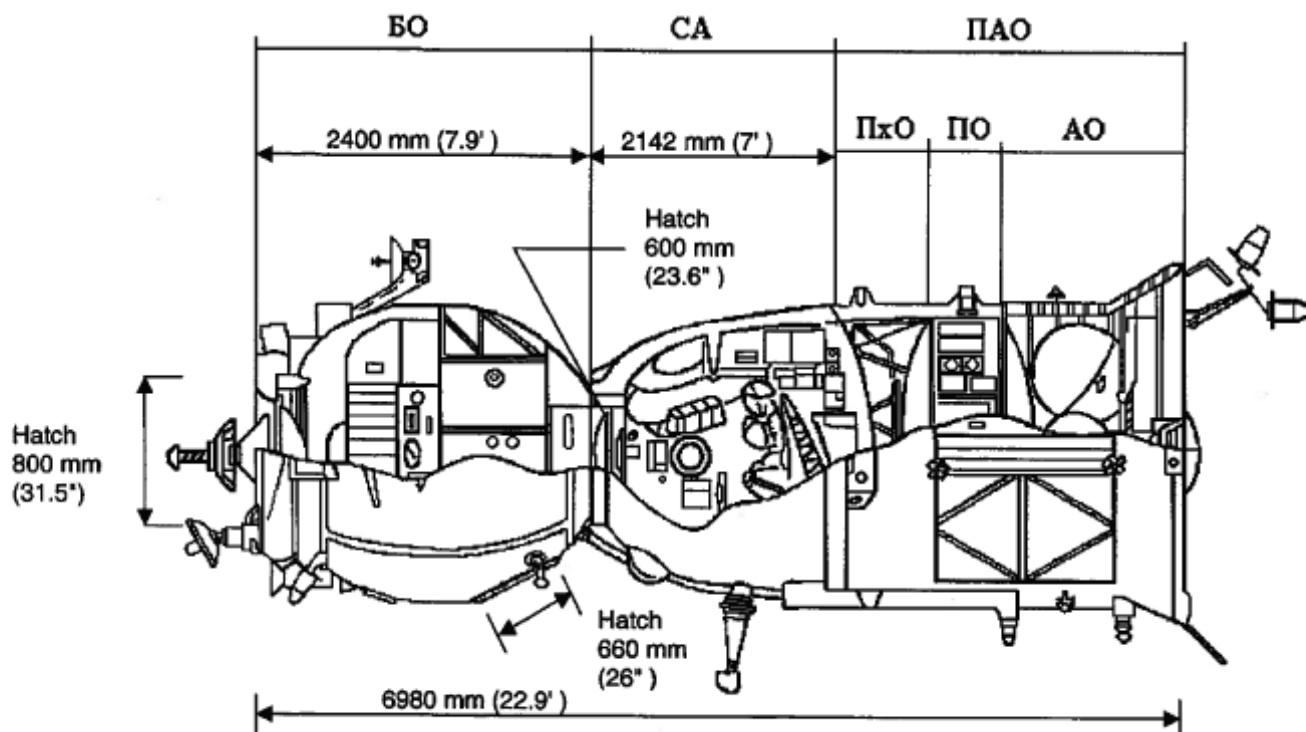
2.2 Voskhod

The Voskhod was a modification of the Vostok to allow a crew of 3 or 2 for EVA. The ejection seat was removed and the entry hatch was converted to a inward opening and pressure sealed hatch. For the EVA mission an external inflatable airlock attached over the Vostok entry hatch. The airlock was called Volga and the EVA hatch opened inward and was pressure sealed. During the Voskhod mission, two (2) EVA crew had trouble closing the EVA hatch.

2.3 Soyuz

The Soyuz spacecraft was built after the Voskhod and was a part of the Russian Lunar Program. The Soyuz TMA, (Figure 2.3) [Reference 18] is the present version used for ISS. It contains upgraded avionics, software and increased size to accommodate larger number of crew members. The Descent Module crew ingress/egress hatch is inward opening and pressure sealed; the hatch is also the transfer path to the attached Orbital Module. The Orbital Module also has a docking/transfer hatch and a crew entry/exit hatch that serves as an EVA hatch. Both of the crew hatches are inward opening and pressure sealed. The transfer hatch is opened and closed manually with a removable crank handle. An outward opening fairing hatch is used to enter or exit the Soyuz Orbital Module when the Soyuz is on the launch vehicle.

Soyuz Exterior Configuration



| | |
|---|-----------------------------------|
| BO – Orbital Module | ПхО – Intermediate Compartment |
| CA – Descent Module | ПГО – Instrumentation Compartment |
| ПАО – Instrumentation/Propulsion Module | АО – Propulsion Compartment |

Figure 2.3 Soyuz Spacecraft

2.4 Progress

The Progress is an unmanned expendable resupply spacecraft. It was derived from the Soyuz to resupply the ISS, and was originally used to resupply the Salyut and Mir Space Stations. The docking and transfer hatch is the same as the Soyuz and is inward opening pressure sealed.

2.5 Almaz

The Almaz, also referred to as TKS, was a military space station project built by what is now called Khrunichev Space Corporation (KhSC) and consisted of a TKS-FGB and a manned transport spacecraft called TKS-VA. The TKS-VA was developed during the U.S. Gemini b/MOL program and had a crew transfer hatch located in the descent capsule heat shield. The heat shield hatch and the crew ingress/egress side hatch opened outward, Figure 2.5.-a. Only unmanned TKS VA test flights were made. The Salyut 2 mission was the first launch of military space station Almaz TKS. It was given the designation Salyut 2 to conceal its true nature, as it was not really a part of the same program as the other Salyut stations. This mission used the Soyuz crew spacecraft as the TKS VA was still in development [Reference 19]

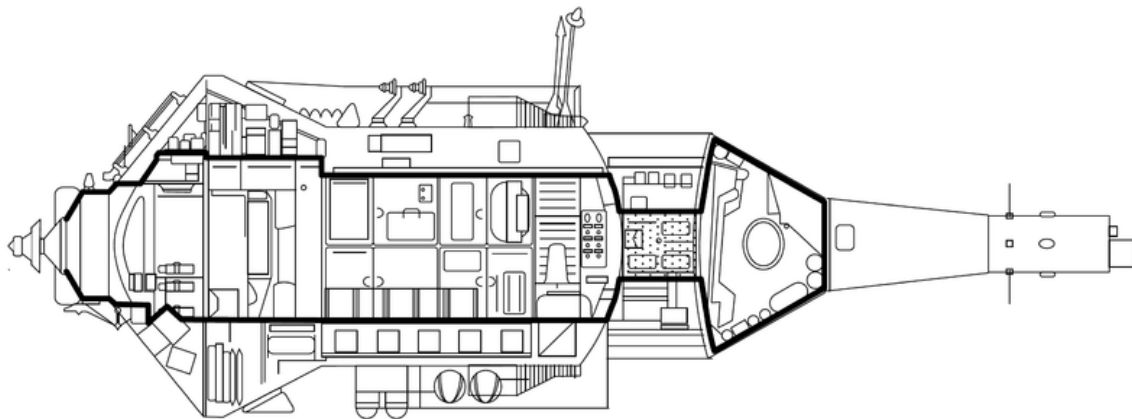


Figure 2.5-a Almaz TKS-FGB



Figure 2.5-b Almaz TKS-VA



Figure 2.5-c Almaz TKS-
Heatshield Hatch

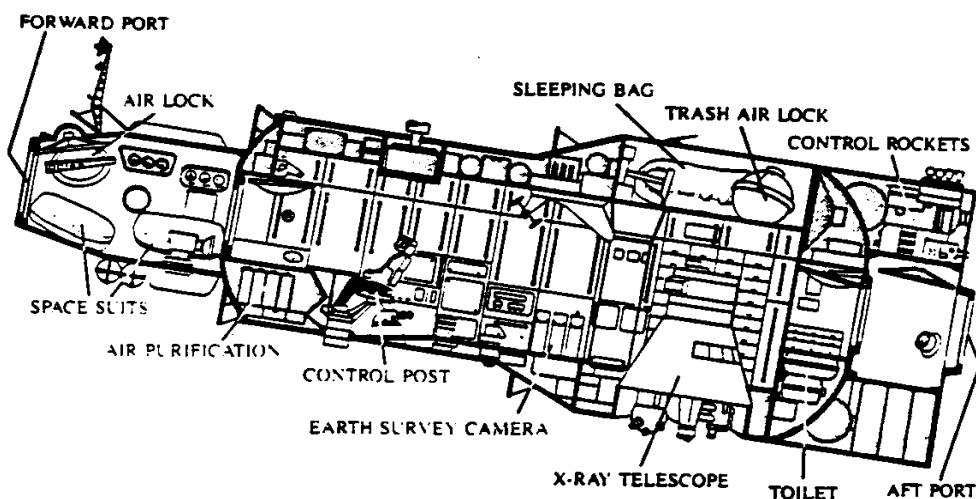
2.6 Salyut

The Salyut was the first space station program undertaken by the Soviet Union, which consisted of a series of nine single-module space stations launched over a period of eleven years from 1971 to 1982. The Salyut was developed by what is now called RSCE and based on the design of a military station module, the Almaz. It initially had one docking port used for crew ingress and egress; the hatch was inward opening and pressure sealed. The Salyut was later modified to have two docking ports, but equipped with the same type of inward opening and pressure sealed hatch. See Figure 2.6 below. [Reference 20]

SOVIET SPACE STATION ANALOGS, Ed. II
Mir 1.0

1.1 GENERAL LAYOUT AND DESIGN OF SPACECRAFT SYSTEM

A. Basic Characteristics of Salyut*:



| | |
|----------------------|---|
| -Length: | 13-15 m |
| -Width: | 4 m |
| -Volume: | 90-100 m ³ usable volume |
| -Weight: | 18,900 kg |
| -Diameter (maximum): | 4.15 m |
| -Largest room: | Working compartment, 40 m ³ |
| -Solar generator: | |
| --Surface area | 60 m ² |
| --Power | 4 KW (increased during flights to 8 KW) |
| -PSAI | 14.7 |
| -Accessible orbits: | |
| --Altitude | 300-400 km |
| --Inclination | 51.6° |
| --Span | 17 m |

*Sources vary slightly with regard to the basic characteristics of the Salyut.

Figure 2.6 Salyut

2.7 Mir

The improved model of Salyut DOS-17K space station with one aft docking port and five ports in a spherical compartment at the forward end of the station became the Core Module of Mir, (Figure 2.7) [Reference 21] sometimes called Base Block.

Kvant 1 was originally designed for Salyut 7 with gyro dynes was added and the Kvant 2 followed. It was based on the Almaz TKS transport spacecraft which had an airlock for EVA. Kristall was later designed for payloads, experiments, and a docking system for Buran which was used by the Space Shuttle Orbiter. Spektr followed and was outfitted for scientific research; the Docking Module was added for Orbiter to dock to, and the last Module added was the Priroda.

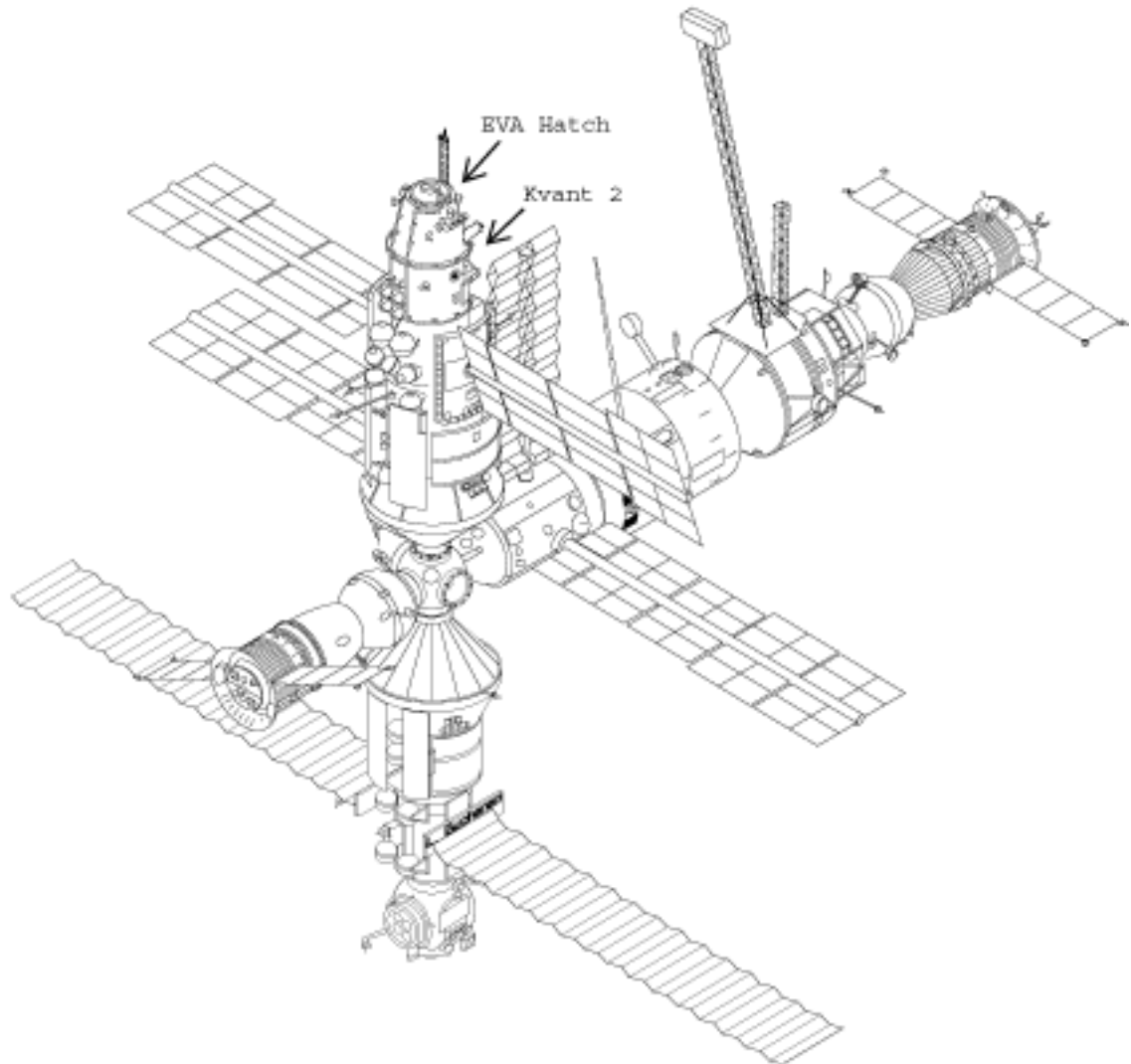


Figure 2.7 Mir

All docking and transfer hatches were inward opening and pressure sealed. The EVA hatch on Kvant 2 was an outward opening hatch which became damaged and was unable to seal in 1990 during an EVA. It was opened when the internal airlock still had some pressure resulting in the rapid opening which bent the hatch hinges.

2.8 Buran

The Buran, designed by RSCE and built by NPO Molniya, was the first Russian spacecraft capable of multiple trips to space and equipped to carry and return payloads. It was developed based upon the U.S. Space Shuttle, and in fact the design specifications enabled Russia to reduce the development cycle time. The Shuttle's aerodynamic shape had been selected by NASA and the U.S. Air Force only after iterative analysis of different configurations from 1968 to 1972. The Russian government decree authorizing development of the Energia-Buran system was issued on 12 February 1976. The launch vehicle booster for Buran was called Energia. The only orbital launch of Buran occurred on 15 November 1988 and performed an automatic landing as it did not have a crew on board.

The Energia booster for Buran used liquid propellant engines instead of the solid rocket motors used on the Shuttle. All of the rocket engines were on the Energia booster for the launch phase of the mission. Improvements were made to the U.S. Space Shuttle design that included tying the forward RCS with the aft RCS and OMS propellant. The Buran was designed for automatic capability and could accommodate heavier payloads. Maximum payload for the Buran was 30,000 as compared to 25,000 for the Shuttle Orbiter.

The crew ingress/egress hatch was located on the side of Buran as in the Space Shuttle Orbiter. However, it was an inward opening pressure sealing hatch, and an outward opening outer hatch with thermal protection, as compared to the one unified hatch for the Shuttle Orbiter. See Figure 2.8, *Buran Orbiter 3D Layout*. The Buran, as is the U.S. Space Shuttle was also fitted with an airlock hatch that opened inward and was pressure sealing to permit EVA. [Reference 22]

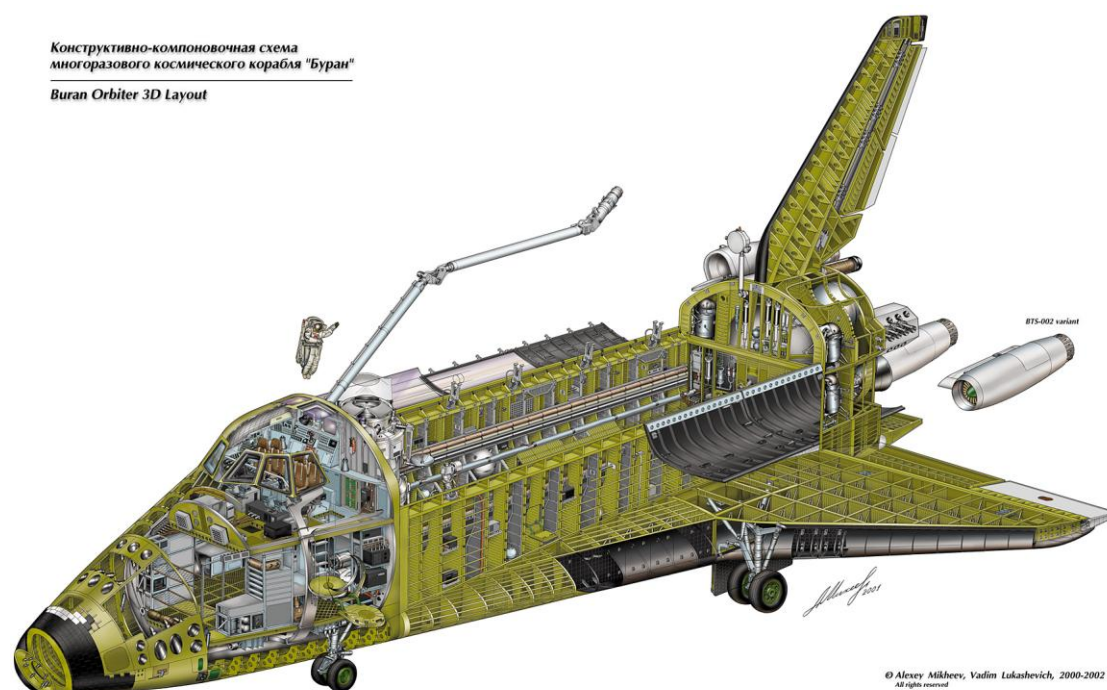


Figure 2.8 Buran

3.0 History of Chinese Spacecraft Crew Hatches

3.1 Shenzhou Spacecraft

The spacecraft closely resembles Soyuz, although it is substantially larger, and unlike the Soyuz, it features a powered orbital module capable of autonomous flight, reference 14. Like Soyuz, Shenzhou consists of three modules: a forward orbital module, a reentry capsule in the middle, and an aft service module. (Figure 3.1) [Reference 23] The reentry module has a crew of three, but is 13% larger than the Soyuz reentry capsule. The orbital module has an 80 cm in diameter EVA hatch and photos from the Shenzhou 7 mission show this to be an inward opening and pressure sealing hatch. On that mission the hatch opening was harder than expected. [Reference 24] At the base of the orbital module is a 70 cm. in diameter hatch providing access to the reentry vehicle. This compares to 60 cm with no hatch on the Soyuz orbital module base. The Soyuz 60 cm. hatch was located on the reentry module compared to the 70 cm. hatch on the Shenzhou reentry module. It appears that the Shenzhou hatches would all be inward opening and pressure sealing like the Soyuz. The fairing crew hatch for Shenzhou would be outward opening like the Soyuz.



Figure 3.1 Shenzhou

4.0 NASA JSC Design and Procedural Standards

There are two (2) design standard requirements for crew hatches included in the NASA JSC Design and Procedural Standard, JPR 8080.5, dated March 8, 2005. [Reference 25] These are Standard Number MS-4, Crew Hatches and Standard Number MS-8, Penetration of Inhabited Spacecraft Compartments. See Appendix B for Standards.

5.0 Future Human Spacecraft

The future design of human space craft crew hatches will require a trade study to weigh the risk of designing an inward opening hatch as compared to an outward opening hatch. A rigorous risk analysis of conditions or hazards that can potentially create a need for an emergency crew egress or emergency ingress of ground personnel for the prelaunch and post landing time periods must be performed. To mitigate the crew safety hazard, a single unified (pressure seal and thermal protection) hatch for quick outward opening is preferred, reference the Apollo CM and Shuttle Orbiter crew ingress/egress hatch. This would be compared to a risk analysis of long mission time exposure to space vacuum where the crew safety hazard is cabin depressurization/loss of cabin atmosphere due to the crew hatch seal leakage or failure. To mitigate the crew safety hazard related to depressurization, an inward opening and pressure sealing hatch is preferred, as cabin pressure tends to seal the hatch verses outward opening where cabin pressure tends to open the hatch. This may result in an inward opening pressure sealing hatch and an outward opening thermal protection hatch, as the Russians designed for Buran.

An earlier look at the performance history of spacecraft hatches has shown that when the crew hatch is also the EVA hatch, an inward opening pressure sealing hatch is preferred. A relevant example can be found with the problem in the MIR Kvant 2 EVA outward opening hatch, also described in Section 2.7 of this document.

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25. JPR 8080.5, JSC Design and Procedural Standard, dated March 8, 2005.

Appendix A

Matrix for Worldwide Spacecraft Crew Hatches

Science Applications International Corporation

Matrix for Worldwide Spacecraft Crew Hatches

| Spacecraft Crew Hatches 9/25/2009 | Type | | | Direction of opening | | Comment |
|--------------------------------------|----------------|------------------|-----|----------------------|-----------------|---|
| | Ingress/Egress | Transfer/Docking | EVA | Inward | Outward | |
| Mercury | | | | | | Failure on MR-2 |
| Entrance Hatch | X | | | | X-Pyro | |
| Escape Hatch | | X | | X | | |
| Vostok | | | | | | |
| Entrance Hatch | X | | | | X-Pyro | |
| Gemini | | | | | | Gemini 4 EVA difficulty opening & closing hatch |
| Ingress/Egress Hatch | X | | X | | X-Man & Pyro | |
| Gemini B/MOL Heatshield | | X | | | X | |
| Voskhod | | | | | | Voskhod 2 difficulty sealing the EVA hatch |
| Entrance Hatch | X | | X | X | | |
| Volga-Airlock Hatch | | | X | X | | |
| Apollo | | | | | | Apollo 1 Unable to egress |
| Block I CM Side Hatch | X | | | X-Inner | X-TPS & Cover | |
| Block 1 CM Docking | | X | | X | | |
| Block II CM Side hatch | X | | X | | X-TPS & Cover | |
| Block II CM Docking | | X | | X | | |
| LM docking | X | X | | X | | |
| LM forward | X | | X | X | | |
| Skylab | | | | | | |
| Airlock(Gemini hatch) | | | X | | X | |
| Docking hatch | X | X | | X | | |
| ISS | | | | | | |
| Quest U.S. airlock | X | | X | X | X-Thermal Cover | |
| Orbiter/PMA-2 docking | | X | | X | | |
| Zeveds SM Aft docking port | | X | | X | | |
| Zara FGB docking port | | X | | X | | |
| HTV /Node-2 Berthing | | X | | X | | |
| ATV Docking | | X | | X | | |
| Piers Docking Comp/Airlock | | X | X | X | | |
| Shuttle | | | | | | STS-80 Nov.28,1996 loose screw jammed EVA hatch gearbox |
| Side hatch | X | | | | X-Man & Pyro | |
| External airlock | | | X | X | | |
| Overhead Escape Panel | X | | | X-Pyro | X-Pyro | |
| External airlock docking | | X | | X | | |
| Soyuz | | | | | | No such thing as "rapid" egress from Soyuz on the pad |
| Descent module | X | | | X | | |
| Orbital module | X | | X | X | | |
| Fairing hatch | X | | | | X | |
| Orbital Module Docking | | X | | X | | |
| Salyut | | | | | | |
| Airlock | | | X | X | | |
| Docking hatches | X | X | | X | | |
| Mir | | | | | | 1990 Kvant 2 EVA hatch damage when opened with slight internal pressure |
| Docking hatches | X | X | | X | | |
| Airlock-Kvant 2 | | | X | | X | |
| Buran | | | | | | |
| Side Hatch | X | | | X | X-TPS | |
| Airlock Hatch | | | X | X | | |
| Shenzhou | | | | | | Shenzhou 7 opening EVA hatch harder than expected |
| Reentry Module | X | | | X | | |
| Orbital Module | X | X | X | X | | |
| Fairing hatch | X | | | | X | |

Appendix B

JSC Design and Procedural Standard No. MS-4
JSC Design and Procedural Standard No. MS-8

**JSC DESIGN AND PROCEDURAL STANDARD
NASA Lyndon B. Johnson Space Center**

| | | | |
|---------------------|---------------------------------|----------------------------------|----------------|
| Crew Hatches | Document No. JPR 8080.5 | Standard No. MS-4 | Page 1 of 2 |
| | Previous Revision 04/01/1991 | Current as of date signed below: | |

STATEMENT OF STANDARD

Crew hatches shall meet the following requirements.

1. OPERATION

- a. Hatches and associated hardware (hinges, latches, actuators, attenuators, seals, etc.) shall be designed for repeated operation.
- b. Hatches shall be designed to be operable on the ground with the vehicle in any ground processing orientation.
- c. Hatches shall be capable of one-handed operation under zero-g conditions.
- d. Hatches shall be capable of being manually closed and opened from both sides.
 - i. Internal hatches shall have in-place provisions for latch-unlatch and opening operations from either side of the hatch.
 - ii. External hatches shall have in-place provisions for latch-unlatch and opening operations from the interior of the hatch, and shall have provisions for latch-unlatch and opening operations from the exterior of the hatch.
- e. Hatch latch actuation shall require two (2) separate and distinct operations to unlatch.
- f. The hatch latch mechanism shall have an indicating system to display hatch latch locked and safe.
- g. Internal hatches shall have a means of pressure equalization and display of pressure delta across the hatch on each side of each hatch.
- h. Opening assist devices shall be provided to break the seals of the hatch to allow the differential pressure across the hatch to reduce to an acceptable level before releasing the hatch to the fully open position.

2. MAINTENANCE

- a. Hatches and associated hardware (hinges, latches, actuators, attenuators, seals, etc.) shall be designed to allow for inspection.
- b. Hatches shall have provisions for ease of removal.
- c. All associated hatch hardware (hinges, latches, actuators, attenuators, seals, etc.) shall be designed to be repairable, replaceable, or both on the ground. If operated during flight, all associated hardware shall be designed to be repairable, replaceable, or both during flight.

Continued next page.

Approval Signature: /s/ Frank Benz
Director, Engineering

Date: 08 March 2005

The requirement set forth in this standard is Lyndon B. Johnson Space Center policy and applies to all human flight equipment developed by the Center. Application to non-human flight or ground equipment is not required unless specifically indicated in the statement of standard. Establishment of the JSC Design and Procedural Standards activity, standards, and policies of application are described in JPD 8080.2.

**JSC DESIGN AND PROCEDURAL STANDARD
NASA Lyndon B. Johnson Space Center**

| | | | |
|---------------------|---------------------------------|----------------------------------|----------------|
| Crew Hatches | Document No. JPR 8080.5 | Standard No. MS-4 | Page 2 of 2 |
| | Previous Revision 04/01/1991 | Current as of date signed below: | |

Continued from previous page

3. SEAL INTEGRITY

- a. The capability shall be provided to leak check between redundant pressure seals without pressurizing/depressurizing the adjacent pressure volumes.
- b. The capability for verification of hatch seal integrity shall be provided on both sides of the hatch.

4. THERMAL AND STRUCTURAL LOADS

- a. Hatches and associated mechanisms shall not be designed to carry primary structural loads.
- b. The design of the structure surrounding hatches used in escape operations shall consider provisions to minimize the probability of jamming which would prevent crew egress following emergency landing or ditching.
- c. Hatches and associated mechanisms shall allow for differential movement between structural frame and the hatch as well as maintain compartment sealing under these conditions.

5. VISIBILITY

- a. Hatches shall incorporate a window designed in accordance with NASA STD 3000.

REMARKS

Refer to MS-8 for hatch requirements related to ground and emergency operations; G-9 Exclusion of Shatterable Material and MS-7 Window and Glass Structure for requirements with respect to the use of glass

The requirement set forth in this standard is Lyndon B. Johnson Space Center policy and applies to all human flight equipment developed by the Center. Application to non-human flight or ground equipment is not required unless specifically indicated in the statement of standard. Establishment of the JSC Design and Procedural Standards activity, standards, and policies of application are described in JPD 8080.2.

2.5-7

**JSC DESIGN AND PROCEDURAL STANDARD
NASA Lyndon B. Johnson Space Center**

| | | | |
|---|------------------------------------|----------------------------------|----------------|
| Penetration Of Inhabited Spacecraft Compartments | Document No. JPR 8080.5 | Standard No. MS-8 | Page 1 of 1 |
| | Previous Revision 04/01/1991 | Current as of date signed below: | |

STATEMENT OF STANDARD

Inhabited spacecraft compartments shall be so designed that all penetrations shall take advantage of normal pressure-induced forces to aid in maintaining vessel structure and cabin pressure integrity.

The primary flight crew ingress/egress hatch used during ground operations shall be designed to be outward opening from the pressurized spacecraft compartment. For designs where it is impractical to have an outward opening hatch, provisions shall be made to rapidly equalize the pressure across the hatch.

Reliable, redundant safety devices shall be provided to prevent inadvertent opening or rapid depressurization on orbit.

REMARKS

Penetrations include ingress/egress and manufacturing access hatches.

The purpose of the outward opening feature specified is to enable rapid egress of the crew from the spacecraft.

Approval Signature: /s/ Frank Benz
Director, Engineering

Date: 08 March 2005

The requirement set forth in this standard is Lyndon B. Johnson Space Center policy and applies to all human flight equipment developed by the Center. Application to non-human flight or ground equipment is not required unless specifically indicated in the statement of standard. Establishment of the JSC Design and Procedural Standards activity, standards, and policies of application are described in JPD 8080.2.

2.5-12